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2.0 Introduction

2.1 Purpose

The objective of this research effort is to develop two physical-based mathematical models of fusion welds. One of these models predicts weld geometry based on weld parameters, while the other relates weld geometry to weld ultimate tensile strength (UTS). When these models reach maturity they will make it possible to predict and tailor UTS based on weld parameters. This effort will make improvements in weld quality, which reduce manufacturing and repair costs, improve safety and reliability, and facilitate the overall manufacturability of current and planned launch vehicles. The effort was accomplished in three phases:

2.2 Phase I Geometry Effects Theory Advancement

1. The current weld geometry/tensile test database has been expanded by completing geometry measurements and tensile tests on thicknesses and materials not evaluated in the first study, and is incorporated in this report.

2. Statistical evaluation of the expanded database has been used to evaluate correlation between test results and theory iterations.

3. Microstructural evaluation has been performed on tensile tested specimens to identify the location and the material composition at the fracture origins, to determine how well the theory worked to predict fracture origin, and to explain discrepancies between results and predictions.

4. Analytical evaluation has been provided to evaluate and suggest modifications to the theory.

5. A simple gauge for measuring weld geometry in the field was developed.

2.3 Phase II (Option 1) Algorithm Improvement and Expansion

1. Existing data analyzed, and additional welds made and analyzed, to provide information for a broader range of weld condition. These welds include other material/thickness combinations, dynamic system response, partial penetration welds, and welds with filler wire addition. NASA's data acquisition was system used to obtain high speed parameter data for all welds made.

2. Evaluation and modification (as required) of the control algorithm for this broader range of weld conditions.

2.4 Phase III (Option II) Algorithm Control Implementation

1. Implementation of the multi-variable control algorithm into the AWCS controller took place.

2. Integration of weld system sensory input for real-time use by the control algorithm. The system is modular and expandable so that it will be able to accept additional input as sensor systems currently under development reach maturity.

3. Weld tests were performed with the system under algorithm control. Testing was done for a variety of weld conditions to assess system performance for both static and dynamic root and cover passes, both with and without wire filler addition.

4. The multi-variable algorithm controlled VPPAW system was be used for a series of welds to demonstrate to NASA personnel, real-time control of weld geometry (crown and root widths for full penetration welds, crown width and height for partial penetration welds) for dynamically changing weld conditions.

5. Real-time crown width and height sensor signals was required for the final two tasks listed above. Completion of these tasks was contingent on the availability of such signals. Since the crown width sensor was not available, NRC ran the model in open loop configuration with results outlined in section 9.

3.0 Expansion Of Weld Geometry / Tensile Test Database

3.1 Inconel 718 Tensile Test Specimens

Rough cut PAW Inconel 718 tensile specimens, made under NASA contract NAS8-38671 "An Investigation Into Geometry and Microstructural Effects Upon the Ultimate Tensile Strengths of Butt Welds" were located and sent for finish machining into dog-bone tensile specimens.

Twenty-six Inconel 718 plates (0.250" thick) were sent for machining of GTA weld preps. These were used for weld parameter development, and to make six usable welds (a wide and narrow each of a normal, mismatched, and peaked weld) for tensile testing.

The first two Inconel 718 GTA welds contained porosity. The first weld (narrow peaked) is still usable by avoiding the porosity locations. The second weld had too much porosity to yield any usable tensile specimens so it was repeated.

The Inconel 718 dog-bone tensile specimens were completed by the NAS machine shop. All were x-rayed to ensure that weld defects had been avoided (all x-rays came out clean). 18 specimens were etched, macrophotographed, and cross-sectional geometries measured. The other 17 had their weld beads shaved flush with the parent metal by the NAS machine shop.

Cross-sectional measurements of all sixty-eight Inconel 718 tensile specimens have been performed. These specimens were tensile tested in the NAS machine shop. The database spreadsheet has been updated with all weld measurements including the results of tensile testing. Table 3.1 is the spreadsheet showing these results.

Definitions relating to weld measurements in table 3.1 are located in appendix VII.

GEOMETRY EFFECTS - GEOMETRY MEASUREMENTS AND TENSILE TEST RESULTS (8-11-95)
FILE C:\GEOM-FX\IN718ALL_1.xls

*** All dimensions are in inches or degrees ***

PHOTO IDENT 2 PIX PER SAMPLE	MTR	THICK	SHAVED	PLATE THICKNESS A	PLATE THICKNESS B	MEASUREMENTS FROM MACROPHOTOGRAPHS: PLATE THICK A	PLATE THICK B	PEAK	MIS MATCH	WELD REINFORCEMENT CROWN	WELD REINFORCEMENT ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	FUSION LINE ANGLES 1/5	2/6	3/7	4/8	MAX CROWN DEPTH	CROWN/ROOT INTERSECT WIDTH	ACTUAL DIMENSIONS (CORRECTED FOR PHOTO MAGNIFICATION): PHOTO MAG.	MIS MATCH	WELD REINFOR CROWN	WELD REINFOR ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	CROWN/ROOT INTERSECT WIDTH	TENSILE TEST RESULTS: Crown W/ Int Width (CW/IW)	UTS (ksi)	2% Y.S (ksi)	% Elong
P3302 A	IN718	0.25	YES	0.269	0.268	2.36	2.35	-2.3	0.075	0.02	0.03	4.24	1.40	10.0	9.0	10.0	20.0	1.34	1.74	8.771	0.009	0.002	0.003	0.483	0.160	0.153	0.198	2.44	119.00	58.80	49.50%
P3302 B	IN718	0.25	YES	0.269	0.268	2.35	2.34	-2.3	0.100	0.00	0.02	4.06	1.42	7.0	5.0	6.0	5.0	1.25	2.00	8.734	0.011	0.000	0.002	0.465	0.163	0.143	0.229	2.03	119.00	58.80	49.50%
P3304 A	IN718	0.25	NO	0.268	0.268	1.44	1.46	-3.0	0.065	0.11	0.21	2.50	0.74	8.5	13.0	4.5	17.0	0.54	1.50	5.410	0.012	0.020	0.039	0.462	0.137	0.100	0.277	1.67	118.40	61.40	43.40%
P3304 B	IN718	0.25	NO	0.268	0.268	1.45	1.45	-3.5	0.070	0.15	0.18	2.50	0.78	8.0	15.5	6.5	10.0	0.74	1.30	5.410	0.013	0.028	0.033	0.462	0.144	0.137	0.240	1.92	118.40	61.40	43.40%
P3307 A	IN718	0.25	NO	0.271	0.268	1.44	1.46	-2.8	0.055	0.18	0.20	2.50	0.76	10.0	16.5	4.0	15.0	0.66	1.51	5.380	0.010	0.033	0.037	0.465	0.141	0.123	0.281	1.66	117.20	61.50	38.90%
P3307 B	IN718	0.25	NO	0.271	0.268	1.45	1.46	-3.8	0.080	0.20	0.19	2.60	0.80	15.0	19.5	10.0	10.0	0.71	1.47	5.399	0.015	0.037	0.035	0.482	0.148	0.132	0.272	1.77	117.20	61.50	38.90%
P3310 A	IN718	0.25	YES	0.264	0.268	2.31	2.34	-2.3	0.045	0.00	0.05	4.08	1.38	8.0	3.0	4.0	10.5	1.30	2.15	8.741	0.005	0.000	0.006	0.467	0.158	0.149	0.246	1.90	115.00	63.60	46.30%
P3310 B	IN718	0.25	YES	0.264	0.268	2.34	2.35	-2.3	0.090	0.00	0.11	4.06	1.20	8.0	5.0	8.0	-2.5	1.16	2.62	8.816	0.010	0.000	0.012	0.461	0.136	0.132	0.297	1.55	115.00	63.60	46.30%
P3312 A	IN718	0.25	NO	0.264	0.267	1.42	1.45	-3.5	0.040	0.19	0.19	2.52	0.78	13.0	17.0	2.5	11.5	0.99	1.60	5.405	0.007	0.035	0.035	0.466	0.144	0.109	0.296	1.58	116.20	65.10	40.90%
P3312 B	IN718	0.25	NO	0.264	0.267	1.43	1.43	-3.0	0.055	0.17	0.20	2.46	0.81	10.5	9.5	8.5	5.5	0.56	1.56	5.386	0.010	0.032	0.037	0.457	0.150	0.104	0.290	1.58	116.20	65.10	40.90%
P3315 A	IN718	0.25	YES	0.263	0.262	2.04	2.07	-3.0	0.005	0.00	0.02	3.76	1.10	4.0	10.0	7.5	1.5	1.13	2.04	7.829	0.001	0.000	0.003	0.480	0.141	0.144	0.261	1.84	114.80	58.00	41.58%
P3315 B	IN718	0.25	YES	0.263	0.262	2.05	2.09	-2.5	0.030	-0.04	0.04	3.73	1.10	20.5	-3.0	17.0	10.0	1.02	2.24	7.886	0.004	-0.005	0.005	0.473	0.139	0.129	0.284	1.67	114.80	58.00	41.58%
P3402 A	IN718	0.25	YES	0.265	0.268	2.31	2.34	-2.0	0.305	0.06	0.04	4.18	1.20	6.0	15.5	-4.0	15.5	0.89	2.52	8.724	0.035	0.007	0.005	0.479	0.138	0.102	0.289	1.66	118.00	74.50	46.00%
P3402 B	IN718	0.25	YES	0.265	0.268	2.31	2.34	-1.8	0.275	0.04	0.13	4.10	1.28	7.0	13.5	13.0	10.0	1.00	2.21	8.724	0.032	0.005	0.015	0.470	0.147	0.115	0.253	1.86	118.00	74.50	46.00%
P3404 A	IN718	0.25	NO	0.268	0.264	1.45	1.44	-2.5	0.210	0.20	0.17	2.45	0.80	4.0	32.0	14.0	8.0	0.52	1.40	5.432	0.039	0.037	0.031	0.451	0.147	0.096	0.258	1.75	117.80	57.40	41.75%
P3404 B	IN718	0.25	NO	0.268	0.264	1.41	1.44	-2.8	0.180	0.20	0.21	2.57	0.73	18.0	15.5	13.0	2.0	0.55	1.42	5.357	0.034	0.037	0.039	0.480	0.136	0.103	0.265	1.81	117.80	57.40	41.75%
P3407 A	IN718	0.25	YES	0.263	0.267	2.30	2.33	-2.0	0.360	0.14	0.05	4.22	1.24	18.0	26.0	0.0	23.5	0.83	2.39	8.736	0.041	0.016	0.006	0.483	0.142	0.095	0.274	1.77	117.20	60.00	46.08%
P3407 B	IN718	0.25	YES	0.263	0.267	2.29	2.38	-2.5	0.275	0.19	0.05	4.28	1.20	12.0	9.0	9.0	7.5	0.75	2.42	8.811	0.031	0.022	0.006	0.486	0.136	0.085	0.275	1.77	117.20	60.00	46.08%
P3410 A	IN718	0.25	NO	0.268	0.262	1.44	1.41	-3.5	0.220	0.20	0.17	2.99	0.73	9.0	40.0	12.5	13.0	0.57	1.26	5.377	0.041	0.037	0.032	0.482	0.136	0.106	0.234	2.06	117.20	56.80	40.30%
P3410 B	IN718	0.25	NO	0.268	0.262	1.42	1.45	-3.5	0.235	0.22	0.16	2.50	0.76	29.5	14.5	16.0	5.0	0.53	1.43	5.415	0.043	0.041	0.030	0.462	0.140	0.098	0.264	1.75	117.20	56.80	40.30%
P3412 A	IN718	0.25	NO	0.263	0.268	1.42	1.43	-3.8	0.240	0.22	0.19	2.49	0.77	29.0	28.0	11.5	14.0	0.67	1.46	5.367	0.045	0.041	0.035	0.464	0.143	0.125	0.272	1.71	115.50	59.90	39.70%
P3412 B	IN718	0.25	NO	0.263	0.268	1.45	1.42	-3.0	0.250	0.21	0.20	2.57	0.75	38.5	12.0	9.5	11.5	0.60	1.31	5.405	0.046	0.039	0.037	0.475	0.139	0.111	0.242	1.96	115.50	59.90	39.70%
P3415 A	IN718	0.25	YES	0.263	0.267	2.31	2.34	-1.5	0.350	0.09	0.00	4.24	1.20	22.0	3.0	6.5	12.0	0.73	2.42	8.774	0.040	0.010	0.000	0.483	0.137	0.083	0.276	1.75	116.50	60.60	47.39%
P3415 B	IN718	0.25	YES	0.263	0.267	2.28	2.31	-1.0	0.380	0.13	0.00	4.16	1.22	14.5	25.5	8.0	17.0	0.86	2.45	8.660	0.044	0.015	0.000	0.480	0.141	0.099	0.283	1.70	116.50	60.60	47.39%
P3502 A	IN718	0.25	NO	0.266	0.269	1.46	1.43	-2.8	0.040	0.11	0.40	2.51	0.93	16.0	19.0	9.0	16.0	0.60	1.18	5.402	0.007	0.020	0.074	0.465	0.172	0.111	0.218	2.13	113.40	57.80	36.50%
P3502 B	IN718	0.25	NO	0.266	0.269	1.44	1.44	-2.6	0.065	0.09	0.41	2.55	0.95	30.0	28.0	16.0	15.0	0.80	1.20	5.383	0.012	0.017	0.076	0.474	0.176	0.149	0.223	2.13	113.40	57.80	36.50%
P3504 A	IN718	0.25	YES	0.267	0.267	2.35	2.34	-3.0	-0.005	0.03	0.04	4.10	1.44	5.0	10.0	10.5	17.0	1.21	1.69	8.783	-0.001	0.003	0.005	0.467	0.164	0.138	0.192	2.43	120.00	59.80	47.13%
P3504 B	IN718	0.25	YES	0.267	0.267	2.33	2.35	-2.8	-0.005	0.04	0.03	4.00	1.56	12.5	2.0	17.0	13.0	1.21	1.72	8.764	-0.001	0.005	0.003	0.456	0.178	0.138	0.196	2.33	120.00	59.80	47.13%
P3507 A	IN718	0.25	NO	0.267	0.268	1.45	1.44	-3.4	0.005	0.12	0.36	2.54	0.92	13.0	30.0	12.0	16.0	0.61	1.27	5.402	0.001	0.022	0.067	0.470	0.170	0.113	0.235	2.00	119.50	62.20	40.50%
P3507 B	IN718	0.25	NO	0.267	0.268	1.46	1.47	-3.6	0.035	0.12	0.39	2.48	0.92	22.5	26.0	12.0	10.0	0.55	1.24	5.477	0.006	0.022	0.071	0.453	0.168	0.100	0.226	2.00	119.50	62.20	40.50%
P3510 A	IN718	0.25	YES	0.268	0.267	2.33	2.35	-3.0	0.065	0.03	0.04	4.12	1.48	22.5	48.0	17.0	10.0	1.10	1.93	8.748	0.007	0.003	0.005	0.471	0.169	0.126	0.221	2.13	118.80	64.40	47.50%
P3510 B	IN718	0.25	YES	0.268	0.267	2.33	2.37	-3.0	0.080	0.00	0.00	4.12	1.36	14.0	33.5	14.0	19.0	1.03	1.84	8.785	0.009	0.000	0.000	0.469	0.155	0.117	0.209	2.24	118.80	64.40	47.50%
P3512 A	IN718	0.25	YES	0.267	0.268	2.35	2.34	-3.0	0.005	0.00	0.04	4.32	1.48	4.0	12.5	17.0	16.0	1.18	1.96	8.766	0.001	0.000	0.005	0.493	0.169	0.135	0.224	2.20	120.30	57.30	46.20%
P3512 B	IN718	0.25	YES	0.267	0.268	2.34	2.38	-2.5	0.055	-0.02	0.03	3.98	1.24	14.5	6.0	7.0	1.0	1.13	2.10	8.822	0.006	-0.002	0.003	0.451	0.141	0.128	0.238	1.90	120.30	57.30	46.20%
P3515 A	IN718	0.25	YES	0.268	0.267	2.29	2.32	-2.3	0.015	0.00	0.02	4.22	1.24	2.5	15.0	4.0	11.0	1.26	2.23	8.617	0.002	0.000	0.002	0.490	0.144	0.146	0.299	1.89	117.30	58.80	41.68%
P3515 B	IN718	0.25	YES	0.268	0.267	2.29	2.33	-2.5	0.040	0.00	0.02	4.18	1.18	19.0	13.0	7.0	7.0	1.18	2.57	8.636	0.005	0.000	0.002	0.484	0.137	0.137	0.298	1.63	117.30	58.80	41.68%
P3702 A	IN718	0.25	NO	0.266	0.263	1.45	1.42	-3.0	0.025	0.18	0.17	2.45	0.70	16.0	31.0	-7.0	11.0	0.57	1.56	5.425	0.005	0.033	0.031	0.452	0.129	0.105	0.288	1.57	117.20	67.70	44.00%
P3702 B	IN718	0.25	NO	0.266	0.263	1.42	1.45	-3.5	0.040	0.21	0.22	2.37	0.69	33.5	14.5	4.5	8.0	0.54	1.61	5.425	0.007	0.039	0.041	0.437	0.127	0.100	0.297	1.47	117.20	67.70	44.00%
P3704 A	IN718	0.25	YES	0.268	0.262	2.35	2.28	-2.5	-0.005	-0.01	0.00	3.90	1.10	12.5	12.5	4.0	8.5	0.94	2.67	8.736	-0.001	-0.001	0.000	0.446	0.126	0.108	0.306	1.46	115.40	56.90	46.30%
P3704 B	IN718	0.25	YES	0.268	0.262	2.34	2.30	-2.8	-0.020	-0.02	0.01	4.06	1.10	13.0	13.5	10.0	6.0	0.97	2.37	8.755	-0.002	-0.002	0.001	0.464	0.126	0.111	0.271	1.71	115.40	56.90	46.30%

Table 3.1

PHOTO IDENT 2 PIX PER SAMPLE	MTR	THICK	SHAVED	PLATE THICKNESS A	PLATE THICKNESS B	MEASUREMENTS FROM MACROPHOTOGRAPHS: PLATE THICK A	PLATE THICK B	PEAK	MIS MATCH	WELD REINFORCEMENT CROWN	WELD REINFORCEMENT ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	FUSION LINE ANGLES 1/5	2/6	3/7	4/8	MAX CROWN DEPTH	CROWN/ROOT INTERSECT WIDTH	ACTUAL DIMENSIONS (CORRECTED FOR PHOTO MAGNIFICATION): PHOTO MAG.	MIS MATCH	WELD REINFOR CROWN	WELD REINFOR ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	CROWN/ROOT INTERSECT WIDTH	TENSILE TEST RESULTS: Crown W/ Int Width (CW/IW)	UTS (ksi)	2% Y.S (ksi)	% Elong
P3707 A	IN718	0.25	NO	0.269	0.264	1.46	1.43	-4.3	0.020	0.19	0.17	2.31	0.64	26.5	27.5	4.5	4.0	0.51	1.58	5.422	0.004	0.035	0.031	0.426	0.118	0.094	0.291	1.46	116.10	65.20	41.90%
P3707 B	IN718	0.25	NO	0.269	0.264	1.42	1.47	-4.5	0.015	0.20	0.21	2.49	0.64	29.0	11.0	3.5	5.5	0.46	1.58	5.422	0.003	0.037	0.039	0.459	0.118	0.085	0.291	1.58	116.10	65.20	41.90%
P3710 A	IN718	0.25	YES	0.264	0.268	2.31	2.31	-3.0	0.025	0.00	0.02	4.10	1.08	6.0	12.0	5.0	5.0	0.80	2.44	8.684	0.003	0.000	0.002	0.472	0.124	0.092	0.281	1.68	118.10	58.90	45.40%
P3710 B	IN718	0.25	YES	0.264	0.268	2.30	2.33	-3.0	0.045	0.03	0.00	3.80	1.16	11.0	6.0	4.0	-1.0	0.96	2.47	8.703	0.005	0.003	0.000	0.437	0.133	0.110	0.284	1.54	118.10	58.90	45.40%
P3712 A	IN718	0.25	YES	0.264	0.268	2.30	2.32	-2.8	0.055	0.00	0.04	3.86	1.12	13.0	14.0	6.0	6.0	0.90	2.40	8.684	0.006	0.000	0.005	0.444	0.129	0.104	0.276	1.61	115.90	58.20	44.68%
P3712 B	IN718	0.25	YES	0.264	0.268	2.31	2.32	-2.5	0.015	0.02	0.02	3.84	1.22	8.0	8.0	2.0	0.5	1.10	2.26	8.703	0.002	0.002	0.002	0.441	0.140	0.126	0.260	1.70	115.90	58.20	44.68%
P3715 A	IN718	0.25	NO	0.265	0.266	1.42	1.42	-3.0	0.045	0.20	0.19	2.45	0.66	27.5	27.0	4.0	7.0	0.50	1.77	5.348	0.008	0.037	0.036	0.458	0.123	0.093	0.331	1.38	115.30	61.60	44.30%
P3715 B	IN718	0.25	NO	0.265	0.266	1.47	1.52	-3.5	0.010	0.18	0.20	2.44	0.71	15.0	8.5	8.0	5.0	0.63	1.60	5.631	0.002	0.032	0.036	0.433	0.126	0.112	0.284	1.53	115.30	61.60	44.30%
P3802 A	IN718	0.25	NO	0.265	0.270	1.43	1.43	-3.5	0.100	0.18	0.15	2.54	0.62	13.0	26.0	3.0	1.5	0.51	1.43	5.346	0.019	0.034	0.028	0.475	0.116	0.095	0.268	1.78	116.60	58.60	38.25%
P3802 B	IN718	0.25	NO	0.265	0.270	1.40	1.45	-3.1	0.100	0.20	0.14	2.40	0.68	22.0	17.0	15.0	1.0	0.39	1.55	5.327	0.019	0.038	0.026	0.451	0.128	0.073	0.291	1.55	116.60	58.60	38.25%
P3804 A	IN718	0.25	YES	0.269	0.264	2.38	2.27	-3.0	-0.020	-0.03	0.00	3.80	1.10	16.0	30.0	2.5	-0.5	0.93	2.84	8.724	-0.002	-0.003	0.000	0.436	0.126	0.107	0.326	1.34	119.10	61.10	44.13%
P3804 B	IN718	0.25	YES	0.269	0.264	2.34	2.28	-2.5	-0.045	0.00	0.00	3.76	1.14	31.5	22.5	8.0	-1.0	0.88	2.66	8.668	-0.005	0.000	0.000	0.434	0.132	0.102	0.307	1.41	119.10	61.10	44.13%
P3807 A	IN718	0.25	YES	0.268	0.263	2.35	2.31	-3.0	-0.020	0.07	0.00	3.78	1.16	14.0	21.0	1.0	4.0	0.84	2.90	8.776	-0.002	0.008	0.000	0.431	0.132	0.096	0.330	1.30	117.20	59.90	42.05%
P3807 B	IN718	0.25	YES	0.268	0.263	2.32	2.25	-3.0	-0.040	0.02	0.04	3.80	1.12	36.5	33.5	3.5	-1.0	0.67	2.85	8.606	-0.005	0.002	0.005	0.442	0.130	0.078	0.331	1.33	117.20	59.90	42.05%
P3810 A	IN718	0.25	NO	0.267	0.264	1.44	1.40	-4.4	0.045	0.19	0.16	2.16	0.67	23.5	32.0	0.0	2.0	0.37	1.78	5.348	0.008	0.036	0.030	0.404	0.125	0.069	0.333	1.21	116.70	57.30	42.75%
P3810 B	IN718	0.25	NO	0.267	0.264	1.42	1.45	-4.5	0.030	0.19	0.16	2.20	0.70	39.0	19.0	9.5	2.0	0.51	1.78	5.405	0.006	0.035	0.030	0.407	0.130	0.094	0.329	1.24	116.70	57.30	42.75%
P3812 A	IN718	0.25	YES	0.266	0.263	2.34	2.28	-3.3	-0.075	0.06	0.00	3.66	1.06	11.0	29.0	1.0	-4.0	0.71	3.05	8.733	-0.009	0.007	0.000	0.419	0.121	0.081	0.349	1.20	117.20	61.40	44.68%
P3812 B	IN718	0.25	YES	0.266	0.263	2.32	2.30	-3.0	-0.060	0.00	0.03	3.78	1.10	28.0	10.0	-2.0	-5.5	0.78	2.91	8.733	-0.007	0.000	0.003	0.433	0.126	0.089	0.333	1.30	117.20	61.40	44.68%
P3815 A	IN718	0.25	NO	0.267	0.264	1.44	1.41	-3.4	0.090	0.17	0.14	2.35	0.66	21.0	36.5	8.0	0.0	0.49	1.82	5.367	0.017	0.032	0.026	0.438	0.123	0.091	0.339	1.29	115.40	57.20	41.70%
P3815 B	IN718	0.25	NO	0.267	0.264	1.40	1.45	-3.8	0.060	0.18	0.15	2.26	0.62	45.5	29.0	15.0	2.0	0.38	1.85	5.367	0.011	0.034	0.028	0.421	0.116	0.071	0.345	1.22	115.40	57.20	41.70%
P3905 A	IN718	0.25	NO	0.268	0.264	1.45	1.43	-4.4	0.030	0.14	0.17	2.49	0.70	24.0	19.0	3.0	8.5	0.51	N/A	5.414	0.006	0.026	0.031	0.460	0.129	0.094	N/A	N/A	118.60	56.60	44.25%
P3905 B	IN718	0.25	NO	0.268	0.264	1.43	1.45	-4.3	0.015	0.10	0.19	2.41	0.79	35.0	9.5	2.5	4.5	0.52	N/A	5.414	0.003	0.018	0.035	0.445	0.146	0.096	N/A	N/A	118.60	56.60	44.25%
P3908 A	IN718	0.25	YES	0.268	0.263	2.34	2.30	-3.0	-0.025	0.02	0.00	3.84	1.08	32.0	16.0	3.0	4.0	0.77	N/A	8.738	-0.003	0.002	0.000	0.439	0.124	0.088	N/A	N/A	118.10	61.40	45.05%
P3908 B	IN718	0.25	YES	0.268	0.263	2.34	2.30	-2.8	-0.050	0.00	0.01	3.94	1.12	39.0	17.0	8.0	-2.0	0.77	N/A	8.738	-0.006	0.000	0.001	0.451	0.128	0.088	N/A	N/A	118.10	61.40	45.05%
P3910 A	IN718	0.25	NO	0.268	0.263	1.43	1.41	-5.0	0.025	0.19	0.12	2.45	0.61	15.0	35.5	3.5	4.0	0.49	N/A	5.348	0.005	0.036	0.022	0.458	0.114	0.092	N/A	N/A	117.90	67.00	41.65%
P3910 B	IN718	0.25	NO	0.268	0.263	1.43	1.46	-5.4	0.010	0.16	0.17	2.24	0.66	36.0	22.5	1.5	4.0	0.35	N/A	5.443	0.002	0.029	0.031	0.412	0.121	0.064	N/A	N/A	117.90	67.00	41.65%
P3913 A	IN718	0.25	YES	0.267	0.263	2.26	2.29	-3.0	-0.035	0.01	0.03	3.80	1.12	27.0	26.0	8.5	4.5	0.92	N/A	8.585	-0.004	0.001	0.003	0.443	0.130	0.107	N/A	N/A	117.30	66.70	45.60%
P3913 B	IN718	0.25	YES	0.267	0.263	2.35	2.30	-3.3	-0.015	0.00	0.00	3.82	1.10	33.0	12.5	4.0	2.0	0.97	N/A	8.774	-0.002	0.000	0.000	0.435	0.125	0.111	N/A	N/A	117.30	66.70	45.60%
P3915 A	IN718	0.25	NO	0.266	0.263	1.43	1.43	-3.4	0.075	0.15	0.16	2.23	0.71	8.0	28.5	3.0	0.0	0.45	N/A	5.406	0.014	0.028	0.030	0.412	0.131	0.083	N/A	N/A	115.90	55.90	46.00%
P3915 B	IN718	0.25	NO	0.266	0.263	1.41	1.43	-4.8	0.045	0.18	0.15	2.28	0.70	28.5	19.0	9.0	2.0	0.42	N/A	5.369	0.008	0.034	0.028	0.425	0.130	0.078	N/A	N/A	115.90	55.90	46.00%
T7302 A	IN718	0.25	NO	0.259	0.260	2.21	2.21	-4.5	-0.070	0.20	0.30	3.64	2.00	5.5	18.0	4.5	3.0	0.55	2.78	8.516	-0.008	0.023	0.035	0.427	0.235	0.065	0.326	1.31	126.20	73.10	38.40%
T7302 B	IN718	0.25	NO	0.259	0.260	2.22	2.24	-4.3	-0.015	0.22	0.32	3.74	2.06	4.5	6.0	2.0	1.0	0.80	2.92	8.593	-0.002	0.026	0.037	0.435	0.240	0.093	0.340	1.28	126.20	73.10	38.40%
T7304 A	IN718	0.25	YES	0.260	0.259	2.25	2.24	-4.5	0.075	0.04	0.00	3.50	1.86	10.0	22.0	-15.0	-9.0	0.72	2.88	8.651	0.009	0.005	0.000	0.405	0.215	0.083	0.333	1.22	127.10	74.90	41.78%
T7304 B	IN718	0.25	YES	0.260	0.259	2.25	2.27	-4.8	0.080	0.02	0.00	3.58	1.86	18.0	21.0	-0.5	-15.0	0.99	2.98	8.709	0.009	0.002	0.000	0.411	0.214	0.068	0.342	1.20	127.10	74.90	41.78%
T7307 A	IN718	0.25	YES	0.260	0.258	2.26	2.23	-4.8	0.035	0.03	0.05	3.58	1.78	12.0	18.0	-13.0	-11.0	0.70	2.94	8.668	0.004	0.003	0.006	0.413	0.205	0.081	0.339	1.22	127.40	63.20	41.60%
T7307 B	IN718	0.25	YES	0.260	0.258	2.26	2.26	-5.0	0.045	0.01	0.02	3.60	1.83	16.0	13.0	-5.0	-7.0	0.80	2.81	8.726	0.005	0.001	0.002	0.413	0.210	0.092	0.322	1.28	127.40	63.20	41.60%
T7310 A	IN718	0.25	NO	0.259	0.260	2.23	2.23	-5.0	-0.025	0.35	0.34	3.64	1.76	17.0	28.0	-11.0	0.0	0.60	2.77	8.593	-0.003	0.041	0.040	0.424	0.205	0.070	0.322	1.31	125.20	71.30	38.20%
T7310 B	IN718	0.25	NO	0.259	0.260	2.22	2.24	-5.0	-0.020	0.37	0.35	3.90	1.84	42.0	14.0	8.0	10.0	0.57	2.93	8.993	-0.002	0.043	0.041	0.454	0.214	0.066	0.341	1.33	125.20	71.30	38.20%
T7312 A	IN718	0.25	YES	0.260	0.259	2.26	2.23	-4.5	0.015	0.00	0.01	3.60	1.96	24.5	22.0	0.0	-6.5	0.66	2.84	8.651	0.002	0.000	0.001	0.416	0.227	0.076	0.328	1.27	124.90	69.80	41.20%
T7312 B	IN718	0.25	YES	0.260	0.259	2.25	2.26	-4.8	0.020	0.03	0.02	3.54	1.90	23	12.0	-6.0	-8.0	0.58	2.92	8.690	0.002	0.003	0.002	0.407	0.219	0.067	0.336	1.21	124.90	69.80	41.20%
T7315 A	IN718	0.25	NO	0.259	0.260	2.24	2.21	-4.8	-0.090	0.34	0.34	3.70	2.00	15.0	15.5	2.5	5.5	0.77	3.05	8.574	-0.010	0.040	0.040	0.432	0.233	0.090	0.356	1.21	126.70	71.10	41.20%
T7315 B	IN718	0.25	NO	0.259	0.260	2.24	2.25	-4.8	-0.125	0.34	0.34	3.90	2.06	13.0	12.0	-2.0	-1.0	0.65	3.10	8.651	-0.014	0.039	0.039	0.451	0.238	0.075	0.358	1.26	126.70	71.10	41.20%
T7403 A	IN718	0.25	NO	0.255	0.259	2.19	2.20	-3.0	-0.500	0.13	0.39	3.70	2.04	7.0	10.0	1.0	1.0	1.00	2.90	8.541	-0.099	0.015	0.046	0.433	0.239	0.117	0.340	1.28	128.30	68.30	41.58%
T7403 B	IN718	0.25	NO	0.255	0.259	2.20	2.24	-3.3	-0.515	0.11	0.39	3.72	2.06	9.0	1.0	-6.5	-4.0	0.77	N/A	8.638	-0.060	0.013	0.045	0.431	0.238	0.089	N/A	N/A	128.30	68.30	41.58%
T7406 A	IN718	0.25	YES	0.258	0.255	2.26	2.22	-2.8	0.685	0.00	0.00	3.86	2.04	13.0	11.5	-9.0	10.0	0.77	N/A	8.733	0.078	0.000	0.000	0.442	0.234	0.088	N/A	N/A	127.70	65.00	37.38%

Table 3.1

PHOTO IDENT 2 PIX PER SAMPLE	MTR	THICK	SHAVED	PLATE THICKNESS		MEASUREMENTS FROM MACROPHOTOGRAPHS: PLATE THICK				WELD REINFORCEMENT		WELD WIDTH		FUSION LINE ANGLES				MAX	CROWN/ ROOT	ACTUAL DIMENSIONS (CORRECTED FOR PHOTO MAGNIFICATION)		WELD REINFORC		WELD WIDTH			CROWN/ ROOT	TENSILE TEST RESULTS: Crown W/ Int Wdth			
				A	B	A	B	PEAK	MIS MATCH	CROWN	ROOT	CROWN	ROOT	1/5	2/6	3/7	4/8	CROWN DEPTH	INTERSECT WIDTH	PHOTO MAG.	MIS MATCH	CROWN	ROOT	CROWN	ROOT	CROWN DEPTH	INTERSECT WIDTH	(CW/IW	UTS (ksi)	2% Y.S (ksi)	% Elong
T7406 B	IN718	0.25	YES	0.258	0.255	2.24	2.22	-2.8	0.700	0.02	0.00	3.66	2.12	14.0	6.0	-15.0	5.5	0.80	2.57	8.694	0.081	0.002	0.000	0.421	0.244	0.092	0.296	1.42	127.70	65.00	37.38%
T7409 A	IN718	0.25	NO	0.255	0.257	2.18	2.18	-2.5	-0.690	0.22	0.40	3.64	2.08	-3.5	12.0	4.5	-7.0	0.74	N/A	8.516	-0.081	0.026	0.047	0.427	0.244	0.087	N/A	N/A	126.70	64.10	37.63%
T7409 B	IN718	0.25	NO	0.255	0.257	2.19	2.22	-2.3	-0.735	0.25	0.38	3.68	2.02	1.0	11.0	12.5	-12.0	0.60	N/A	8.613	-0.085	0.029	0.044	0.427	0.235	0.070	N/A	N/A	126.70	64.10	37.63%
T7412 A	IN718	0.25	NO	0.254	0.259	2.21	2.22	-2.8	-0.625	0.23	0.40	3.60	2.10	13.0	11.0	-1.0	0.0	0.55	N/A	8.635	-0.072	0.027	0.046	0.417	0.243	0.064	N/A	N/A	126.60	65.50	33.05%
T7412 B	IN718	0.25	NO	0.254	0.259	2.20	2.21	-2.8	-0.600	0.24	0.36	3.66	2.12	15.5	10.0	-8.0	-7.0	0.76	N/A	8.596	-0.070	0.028	0.042	0.426	0.247	0.088	N/A	N/A	126.60	65.50	33.05%
T7415 A	IN718	0.25	YES	0.260	0.255	2.26	2.21	-2.0	0.505	0.10	0.04	3.74	2.20	13.0	7.5	-11.0	2.0	0.73	N/A	8.680	0.058	0.012	0.005	0.431	0.253	0.084	N/A	N/A	120.70	65.40	26.40%
T7415 B	IN718	0.25	YES	0.260	0.255	2.23	2.22	-2.5	0.520	0.08	0.03	3.69	2.17	16.0	-3.5	-7.0	2.0	0.75	N/A	8.641	0.060	0.009	0.003	0.427	0.251	0.087	N/A	N/A	120.70	65.40	26.40%
T7503 A	IN718	0.25	NO	0.260	0.257	2.22	2.19	-15.3	-0.010	0.22	0.38	3.66	1.86	8.0	16.0	-7.0	-5.0	0.67	N/A	8.530	-0.001	0.026	0.045	0.429	0.218	0.079	N/A	N/A	125.70	44.00	41.05%
T7503 B	IN718	0.25	NO	0.260	0.257	2.21	2.19	-14.8	0.000	0.22	0.39	3.67	1.90	17.0	7.0	0.0	-3.0	0.64	N/A	8.511	0.000	0.026	0.046	0.431	0.223	0.075	N/A	N/A	125.70	44.00	41.05%
T7506 A	IN718	0.25	YES	0.258	0.260	2.27	2.26	-15.5	-0.120	0.04	0.00	3.58	2.00	15.0	23.0	-7.5	-16.0	0.72	N/A	8.745	-0.014	0.005	0.000	0.409	0.229	0.082	N/A	N/A	122.60	35.20	41.93%
T7506 B	IN718	0.25	YES	0.258	0.260	2.24	2.27	-15.5	-0.065	0.02	0.00	3.56	2.00	12.0	13.0	-5.0	-8.0	0.83	N/A	8.707	-0.007	0.002	0.000	0.409	0.230	0.095	N/A	N/A	122.60	35.20	41.93%
T7508 A	IN718	0.25	YES	0.258	0.259	2.26	2.26	-15.0	-0.150	0.04	-0.07	3.63	2.00	11.0	13.5	-11.0	-16.0	0.83	N/A	8.743	-0.017	0.005	-0.008	0.415	0.229	0.095	N/A	N/A	125.80	30.60	43.03%
T7508 B	IN718	0.25	YES	0.258	0.259	2.24	2.26	-15.3	-0.100	0.03	-0.08	3.76	2.06	11.0	13.0	-9.0	-14.0	0.65	N/A	8.704	-0.011	0.003	-0.009	0.432	0.237	0.075	N/A	N/A	125.80	30.60	43.03%
T7511 A	IN718	0.25	NO	0.259	0.258	2.23	2.20	-15.5	0.165	0.22	0.22	3.66	2.06	34.0	15.0	-10.5	5.0	0.60	N/A	8.569	0.019	0.026	0.026	0.427	0.240	0.070	N/A	N/A	123.90	39.40	40.53%
T7511 B	IN718	0.25	NO	0.259	0.258	2.23	2.23	-15.0	0.125	0.28	0.27	3.64	2.18	20.0	9.0	-1.0	5.0	0.77	N/A	8.627	0.014	0.032	0.031	0.422	0.253	0.089	N/A	N/A	123.90	39.40	40.53%
T7514 A	IN718	0.25	NO	0.260	0.257	2.24	2.20	-16.0	0.110	0.28	0.27	3.57	1.96	15.5	13.0	-2.5	7.5	0.72	N/A	8.588	0.013	0.033	0.031	0.416	0.228	0.084	N/A	N/A	124.50	33.70	43.58%
T7514 B	IN718	0.25	NO	0.260	0.257	2.22	2.21	-15.8	0.095	0.26	0.28	3.64	2.00	43.5	19.0	3.5	-3.0	0.68	N/A	8.569	0.011	0.030	0.033	0.425	0.233	0.079	N/A	N/A	124.50	33.70	43.58%
T7701 A	IN718	0.25	NO	0.260	0.261	2.27	2.24	-4.0	0.155	0.16	0.26	3.16	1.32	13.5	11.0	-1.0	-8.0	0.72	2.26	8.656	0.018	0.018	0.030	0.365	0.152	0.083	0.261	1.40	73.60	######	42.05%
T7701 B	IN718	0.25	NO	0.260	0.261	2.22	2.28	-4.0	0.125	0.16	0.33	2.99	1.36	12.5	8.0	-3.0	5.0	0.84	2.36	8.637	0.014	0.019	0.038	0.346	0.157	0.097	0.273	1.27	73.60	######	40.53%
T7704 A	IN718	0.25	NO	0.259	0.262	2.26	2.27	-4.5	0.140	0.27	0.35	3.20	1.34	19.0	15.0	-4.0	3.0	0.70	2.14	8.695	0.016	0.031	0.040	0.368	0.154	0.081	0.246	1.50	65.80	######	39.00%
T7704 B	IN718	0.25	NO	0.259	0.262	2.23	2.27	-4.3	0.145	0.26	0.40	3.18	1.46	23.0	7.0	-3.0	4.0	0.70	2.12	8.637	0.017	0.030	0.046	0.368	0.169	0.081	0.245	1.50	65.80	######	39.15%
T7706 A	IN718	0.25	YES	0.262	0.259	2.29	2.27	-4.0	-0.240	0.02	0.00	3.80	1.27	8.0	20.5	2.0	-9.0	0.73	2.17	8.752	-0.027	0.002	0.000	0.434	0.145	0.083	0.248	1.75	127.60	71.60	39.30%
T7706 B	IN718	0.25	YES	0.262	0.259	2.27	2.26	-4.3	-0.170	0.00	0.02	3.19	1.42	16.0	6.0	-3.0	-7.0	0.77	2.41	8.695	-0.020	0.000	0.002	0.367	0.163	0.089	0.277	1.32	127.60	71.60	39.30%
T7709 A	IN718	0.25	YES	0.263	0.259	2.30	2.27	-4.0	-0.120	0.00	0.00	3.26	1.29	3.5	17.0	0.0	-6.5	0.75	2.23	8.755	-0.014	0.000	0.000	0.372	0.147	0.086	0.255	1.46	123.70	9.03	39.63%
T7709 B	IN718	0.25	YES	0.263	0.259	2.29	2.27	-4.3	-0.165	0.02	0.00	3.21	1.39	12.0	11.0	4.5	-4.0	0.71	2.16	8.736	-0.019	0.002	0.000	0.367	0.159	0.081	0.247	1.49	123.70	9.03	39.63%
T7712 A	IN718	0.25	NO	0.259	0.262	2.23	2.26	-4.0	0.055	0.26	0.34	3.18	1.11	16.0	17.0	1.0	0.0	0.74	2.21	8.618	0.006	0.030	0.039	0.369	0.129	0.086	0.256	1.44	128.40	72.90	38.25%
T7712 B	IN718	0.25	NO	0.259	0.262	2.22	2.26	-4.0	0.035	0.03	0.04	3.10	1.10	18.0	11.0	5.5	0.0	0.76	2.51	8.999	0.004	0.003	0.005	0.361	0.128	0.088	0.292	1.24	128.40	72.90	38.25%
T7714 A	IN718	0.25	YES	0.262	0.260	2.30	2.26	-3.8	-0.010	0.00	0.01	3.16	1.31	4.0	7.0	-4.5	-9.5	0.71	2.30	8.736	-0.001	0.000	0.001	0.362	0.150	0.081	0.263	1.37	125.50	70.90	39.95%
T7714 B	IN718	0.25	YES	0.262	0.260	2.28	2.24	-3.8	0.005	0.00	0.01	3.20	1.44	6.0	16.0	-5.0	5.0	0.70	2.26	8.659	0.001	0.000	0.001	0.370	0.166	0.081	0.261	1.42	125.50	70.90	39.95%
T7803 A	IN718	0.25	NO	0.258	0.261	2.22	2.24	-4.8	0.635	0.33	0.30	3.32	1.16	24.5	12.0	-24.0	11.0	0.65	2.34	8.993	0.074	0.038	0.035	0.386	0.135	0.076	0.272	1.42	127.40	72.10	35.83%
T7803 B	IN718	0.25	NO	0.258	0.261	2.20	2.25	-4.5	0.640	0.38	0.33	3.33	1.16	29.5	21.0	-12.5	12.0	0.62	2.30	8.574	0.075	0.044	0.038	0.388	0.135	0.072	0.268	1.45	127.40	72.10	35.83%
T7805 A	IN718	0.25	YES	0.259	0.262	2.29	2.23	-4.5	-0.810	0.02	-0.06	3.47	1.23	5.0	25.5	12.0	-21.0	0.70	2.42	8.676	-0.093	0.002	-0.007	0.400	0.142	0.081	0.279	1.43	120.40	65.50	24.43%
T7805 B	IN718	0.25	YES	0.259	0.262	2.26	2.25	-4.3	-0.775	0.05	-0.12	3.33	1.08	9.5	34.5	11.0	-25.0	0.72	2.26	8.656	-0.090	0.006	-0.014	0.385	0.125	0.083	0.261	1.47	120.40	65.50	24.43%
T7809 A	IN718	0.25	NO	0.259	0.261	2.27	2.26	-4.3	0.800	0.33	0.20	3.30	1.07	23.0	15.5	-28.0	8.0	0.56	2.37	8.712	0.092	0.038	0.023	0.379	0.123	0.064	0.272	1.39	123.30	63.60	27.25%
T7809 B	IN718	0.25	NO	0.259	0.261	2.24	2.28	-4.5	0.760	0.33	0.43	3.44	1.20	25.0	13.5	-23.0	9.0	0.71	2.38	8.692	0.087	0.038	0.049	0.396	0.138	0.082	0.274	1.45	123.30	63.60	27.25%
T7812 A	IN718	0.25	YES	0.262	0.259	2.28	2.23	-4.5	-0.590	0.02	-0.04	3.34	1.38	26.5	35.5	3.0	-16.0	0.88	2.23	8.656	-0.068	0.002	-0.005	0.386	0.159	0.102	0.258	1.50	128.90	66.60	37.80%
T7812 B	IN718	0.25	YES	0.262	0.259	2.26	2.28	-4.8	-0.635	0.00	-0.01	3.66	1.17	40.0	35.5	-3.5	-19.0	0.68	2.24	8.714	-0.073	0.000	-0.001	0.420	0.134	0.078	0.257	1.63	128.90	66.60	37.80%
T7815 A	IN718	0.25	NO	0.258	0.261	2.25	2.26	-3.5	0.580	0.37	0.25	3.50	1.21	40.0	32.0	-13.0	-4.5	0.74	2.37	8.690	0.067	0.043	0.029	0.403	0.139	0.085	0.273	1.48	127.40	65.10	37.20%
T7815 B	IN718	0.25	NO	0.258	0.261	2.24	2.27	-3.5	0.590	0.32	0.30	3.32	1.34	27.5	14.0	-9.0	2.0	0.74	2.62	8.690	0.068	0.037	0.035	0.382	0.154	0.085	0.302	1.27	127.40	65.10	37.20%
T7902 A	IN718	0.25	YES	0.260	0.256	2.25	2.21	-9.8	0.000	0.00	0.14	3.89	1.05	12.0	16.0	-1.0	-6.0	0.67	2.45	8.643	0.000	0.000	0.016	0.450	0.121	0.078	0.283	1.59	118.00	68.30	39.65%
T7902 B	IN718	0.25	YES	0.260	0.256	2.25	2.22	-9.8	0.050	0.01	0.10	3.81	1.03	18.0	12.0	-12.0	-5.0	0.69	2.63	8.663	0.006	0.001	0.012	0.440	0.119	0.080	0.304	1.45	118.00	68.30	39.65%
T7904 A	IN718	0.25	NO	0.257	0.260	2.19	2.20	-9.5	-0.140	0.38	0.36	3.99	1.12	15.5	15.0	-1.5	-8.5	0.54	2.61	8.491	-0.016	0.045	0.042	0.423	0.132	0.064	0.307	1.38	124.50	75.70	36.95%
T7904 B	IN718	0.25	NO	0.257	0.260	2.21	2.24	-10.0	-0.005	0.44	0.30	3.77	1.12	19.0	22.0	-12.0	-10.0	0.73	2.38	8.607	-0.001	0.051	0.035	0.438	0.130	0.085	0.277	1.58	124.50	75.70	36.95%
T7907 A	IN718	0.25	YES	0.260	0.256	2.28	2.25	-12.0	0.000	0.01	0.10	4.02	1.02	15.0	16.0	-5.5	-14.0	0.79	2.57	8.779	0.000	0.001	0.011	0.458	0.116	0.090	0.293	1.56	127.80	34.50	41.95%
T7907 B	IN718	0.25	YES	0.260	0.256	2.26	2.25	-12.8	0.040	0.04	0.05	3.70	0.96	20.0	15.0	-20.0	-13.0	0.65	2.44	8.740	0.005	0.005	0.006	0.423	0.110	0.074	0.279	1.52	127.80	34.50	41.95%

Table 3.1

PHOTO IDENT: 2 PIX PER SAMPLE	MTR	THICK	SHAVED	PLATE THICKNESS A	PLATE THICKNESS B	MEASUREMENTS FROM MACROPHOTOGRAPHS: PLATE THICK A	PLATE THICK B	PEAK	MIS MATCH	WELD REINFORCEMENT CROWN	WELD REINFORCEMENT ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	FUSION LINE ANGLES 1/5	2/6	3/7	4/8	MAX CROWN DEPTH	CROWN/ROOT INTERSECT WIDTH	ACTUAL DIMENSIONS (CORRECTED FOR PHOTO MAGNIFICATION): PHOTO MAG.	MIS MATCH	WELD REINFOR CROWN	WELD REINFOR ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	CROWN/ROOT INTERSECT WIDTH	TENSILE TEST RESULTS: Crown W/ Int Widt (CW/IW	UTS (ksi)	.2% Y.S (ksi)	% Elong
T7910 A	IN718	0.25	NO	0.256	0.259	2.17	2.21	-12.5	0.010	0.39	0.25	4.10	0.93	30.0	5.0	-11.0	-3.0	0.54	N/A	8.505	0.001	0.046	0.029	0.482	0.109	0.063	N/A	N/A	126.10	57.00	40.60%
T7910 B	IN718	0.25	NO	0.256	0.259	2.17	2.24	-11.5	0.035	0.39	0.32	3.84	1.08	18.0	28.0	1.0	5.0	0.60	N/A	8.563	0.004	0.046	0.037	0.448	0.126	0.070	N/A	N/A	126.10	57.00	40.60%
T7912 A	IN718	0.25	NO	0.256	0.259	2.18	2.19	-11.5	0.015	0.38	0.29	4.05	1.12	16.5	15.0	-2.0	0.0	0.58	N/A	8.485	0.002	0.045	0.034	0.477	0.132	0.068	N/A	N/A	126.70	60.70	39.88%
T7912 B	IN718	0.25	NO	0.256	0.259	2.16	2.22	-11.3	0.055	0.36	0.30	4.15	1.05	14.0	19.0	-1.0	0.0	0.57	N/A	8.505	0.006	0.042	0.035	0.488	0.123	0.067	N/A	N/A	126.70	60.70	39.88%
T7915 A	IN718	0.25	YES	0.258	0.256	2.25	2.22	-6.5	-0.060	0.00	0.01	3.88	0.97	18.0	31.0	-16.0	-14.0	0.98	2.55	8.696	-0.007	0.000	0.001	0.446	0.112	0.113	0.293	1.52	122.60	62.80	42.15%
T7915 B	IN718	0.25	YES	0.258	0.256	2.23	2.23	-7.8	-0.010	0.02	-0.02	4.32	1.21	39.0	16.5	-8.0	0.0	0.92	2.83	8.677	-0.001	0.002	-0.002	0.498	0.139	0.106	0.326	1.53	122.60	62.80	42.15%

Table 3.1

3.2 HP9-4-30 Tensile Test Specimens

PAW and GTAW HP9-4-30 welded plates, made under NASA contract NAS8-38671 "An Investigation Into Geometry and Microstructural Effects Upon the Ultimate Tensile Strengths of Butt Welds" were located and sent for machining into dog-bone tensile specimens.

Machining, polishing, etching, macrophotography, geometry measurements, and tensile testing has been completed for all twelve 0.45" thick HP9-4-30 tensile specimens. All six of the unshaved specimens failed in parent metal. Of the six shaved specimens, four failed in parent metal, one failed in the HAZ, and one failed in the weld metal. The spreadsheet showing the measurements for the HP9-4-30 is located in Table 3.2

GEOMETRY EFFECTS - GEOMETRY MEASUREMENTS AND TENSILE TEST RESULTS (6-17-94)
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*** All dimensions in inches or degrees ***

PHOTO IDENT: 2 PIX PER SAMPLE	MTR	THICK	SHAV	PLATE THICKNESS A	PLATE THICKNESS B	PEAKING	WELD WIDTH CROWN	WELD WIDTH ROOT	FUSION LINE ANGLES 1/5	FUSION LINE ANGLES 2/6	FUSION LINE ANGLES 3/7	FUSION LINE ANGLES 4/8	MIS-MATCH	WELD REINFORCEM CROWN	WELD REINFORCEM ROOT	WELD CROWN
P2801 A	HP	0.45	Yes	0.447	0.447	-0.25	2.36	0.71	44.0	57.0	-0.5	-5.0	-0.057	0.000	0.000	0.593
P2801 B	HP	0.45	Yes	0.447	0.447	-0.50	2.31	0.66	45.5	53.5	7.5	-1.0	-0.052	0.000	0.000	0.587
P2802 A	HP	0.45	No	0.447	0.446	-0.50	2.33	0.66	42.5	48.0	1.0	3.5	-0.057	0.037	0.049	0.543
P2802 B	HP	0.45	No	0.447	0.446	-0.75	2.50	0.73	47.0	51.0	-8.5	0.0	-0.059	0.039	0.060	0.580
P2804 A	HP	0.45	No	0.446	0.447	-1.00	2.30	0.76	36.0	28.5	3.0	-4.0	-0.060	0.042	0.051	0.538
P2804 B	HP	0.45	No	0.446	0.447	-0.75	2.24	0.78	23.5	24.0	-2.5	-8.0	-0.058	0.044	0.053	0.520
P2805 A	HP	0.45	Yes	0.447	0.447	-1.25	2.13	0.63	33.5	31.5	-18.0	-14.0	-0.055	0.000	0.000	0.543
P2805 B	HP	0.45	Yes	0.447	0.447	-1.00	2.28	0.57	43.0	52.0	9.5	-7.5	-0.048	0.000	0.000	0.581
P2806 A	HP	0.45	Yes	0.447	0.447	-0.75	2.27	0.89	42.0	45.0	-1.5	0.0	-0.051	0.000	0.000	0.581
P2806 B	HP	0.45	Yes	0.447	0.447	-1.25	2.13	0.79	30.0	52.5	11.0	-1.0	-0.050	0.000	0.000	0.544
P2807 A	HP	0.45	No	0.446	0.447	-1.25	2.32	0.78	38.5	39.0	-1.0	-2.0	-0.055	0.042	0.054	0.542
P2807 B	HP	0.45	No	0.446	0.447	-0.75	2.37	0.77	42.0	38.0	-5.0	-7.0	-0.051	0.044	0.053	0.548
P3202 A	HP	0.45	Yes	0.448	0.447	-0.50	1.73	0.46	35.0	41.0	-11.0	-18.5	-0.041	0.000	0.000	0.612
P3202 B	HP	0.45	Yes	0.448	0.447	-1.00	2.11	0.61	33.0	36.0	8.0	1.0	-0.044	0.000	0.000	0.530
P3205 A	HP	0.45	Yes	0.447	0.447	-1.50	2.23	0.80	35.0	46.0	-1.0	-8.5	-0.046	0.000	0.000	0.570
P3205 B	HP	0.45	Yes	0.447	0.447	-1.25	1.97	0.71	33.5	46.0	9.5	3.0	-0.043	0.000	0.000	0.498
P3207 A	HP	0.45	Yes	0.447	0.447	-1.25	2.07	0.74	43.0	44.0	-4.0	-5.0	-0.052	0.000	0.000	0.523
P3207 B	HP	0.45	Yes	0.447	0.447	-1.75	2.19	0.76	44.0	48.0	11.5	3.0	-0.048	0.000	0.000	0.563
P3210 A	HP	0.45	No	0.447	0.447	-1.50	2.23	0.70	54.0	49.0	4.0	0.0	-0.051	0.065	0.110	0.521
P3210 B	HP	0.45	No	0.447	0.447	-1.75	2.29	0.76	28.5	41.5	16.0	-13.5	-0.047	0.065	0.113	0.530
P3213 A	HP	0.45	No	0.447	0.447	-1.50	2.20	0.80	44.0	46.0	3.0	2.0	-0.052	0.056	0.114	0.511
P3213 B	HP	0.45	No	0.447	0.447	-1.25	2.21	0.76	36.0	42.5	4.5	-12.0	-0.048	0.058	0.112	0.516
P3215 A	HP	0.45	No	0.447	0.446	-1.50	2.20	0.73	48.0	51.5	-3.0	-20.0	-0.055	0.075	0.049	0.516
P3215 B	HP	0.45	No	0.447	0.446	-1.50	2.30	0.73	43.0	50.0	1.0	-14.5	-0.052	0.076	0.044	0.531

Table 3.2

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PHOTO IDENT: 2 PIX PER SAMPLE	) WIDTH ROOT	CROWN DEPTH	CROWN/ROOT INTERSECT WIDTH	TENSILE TEST RESULTS UTS (ksi)	.2% Y.S (ksi)	% Elong		
P2801 A	0.178	0.131	0.462	222.0	184.2	TBD*	FAILED IN HAZ (has widest crown width and depth)	
P2801 B	0.168	0.091	0.366	222.0	184.2	TBD*	FAILED IN HAZ (has widest crown width and depth)	Machined Under Flush
P2802 A	0.154	0.117	0.487	221.0	191.9	TBD*	Failed In Base Metal	
P2802 B	0.169	0.116	0.524	221.0	191.9	TBD*	Failed In Base Metal	
P2804 A	0.178	0.115	0.514	220.0	184.0	TBD*	Failed In Base Metal	
P2804 B	0.181	0.111	0.508	220.0	184.0	TBD*	Failed In Base Metal	
P2805 A	0.160	0.097	0.408	206.0	184.0	TBD*	FAILED IN THE WELD METAL	
P2805 B	0.145	0.099	0.423	206.0	184.0	TBD*	FAILED IN THE WELD METAL	
P2806 A	0.228	0.087	0.456	222.0	191.8	TBD*	Failed In Base Metal	Machined Under Flush
P2806 B	0.202	0.095	0.404	222.0	191.8	TBD*	Failed In Base Metal	Machined Under Flush
P2807 A	0.182	0.115	0.514	220.0	184.0	TBD*	Failed In Base Metal	
P2807 B	0.178	0.116	0.379	220.0	184.0	TBD*	Failed In Base Metal	
P3202 A	0.163	0.057	0.552	233.0	195.5	TBD*	Failed In Base Metal	
P3202 B	0.153	0.073	0.410	233.0	195.5	TBD*	Failed In Base Metal	
P3205 A	0.204	0.087	0.347	227.0	194.0	TBD*	Failed In Base Metal	
P3205 B	0.179	0.086	0.336	227.0	194.0	TBD*	Failed In Base Metal	
P3207 A	0.187	0.101	0.407	227.0	184.4	TBD*	Failed In Base Metal	
P3207 B	0.195	0.100	0.331	227.0	184.4	TBD*	Failed In Base Metal	Crown Machined Under Flush
P3210 A	0.163	0.147	0.390	224.0	194.7	TBD*	Failed In Base Metal	
P3210 B	0.176	0.123	0.375	224.0	194.7	TBD*	Failed In Base Metal	
P3213 A	0.186	0.130	0.351	226.0	194.7	TBD*	Failed In Base Metal	
P3213 B	0.177	0.124	0.341	226.0	194.7	TBD*	Failed In Base Metal	
P3215 A	0.171	0.136	0.427	231.0	189.7	TBD*	Failed In Base Metal	
P3215 B	0.168	0.113	0.376	231.0	189.7	TBD*	Failed In Base Metal	

Table 3.2

3.3 2219-T87 Aluminum Test Specimens

Welding of the 0.75" thick 2219-T87 aluminum was completed. This consisted of 6 VPPA welds and 6 GTA welds. Seventy-two 0.75" thick 2219-T87 aluminum tensile specimens have been machined, including removal of the weld crown and root reinforcement for thirty-six of the samples.

Thirty-six of the 0.75" thick 2219-T87 aluminum tensile specimens have had their cross sections polished, etched, and photographed (2 photographs per specimen). Geometry measurements for these thirty-six specimens were performed.

Thirty-four of the 0.75" thick 2219-T87 aluminum tensile specimens have been tensile tested and their ultimate tensile strengths (UTS), yield strengths, and % elongations have been obtained. Overall so far, UTS values have been higher for GTA welds than for VPPA welds.

Machining, polishing, etching, macrophotography, geometry measurements and tensile testing were performed for all seventy-two 0.75" thick 2219-T87 aluminum tensile specimens. In general the GTA welds were stronger than the VPPA welds, but had more UTS variations and a larger UTS range. The following values were obtained for GTA welds and VPPA welds respectively:

Average UTS: 39.1 ksi and 36.1 ksi;
Standard deviation of UTS: 5.5 ksi and 4.0 ksi;
Range of UTS: 25.3 to 45.2 ksi and 27.4 to 41.0 ksi.

Results of these measurements are contained in the spreadsheet in Table 3.3.

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PHOTO IDENT: 2 PIX PER SAMPLE	CRN/ROOT INTERSEC. WIDTH	PHOTO MAG.	MISMATCH	WELD REINFORCEM. CROWN	WELD REINFORCEM. ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	ROWN/ROC INTERSECT. WIDTH	UTS (ksi)	.2% Y.S. (ksi)	% Elong
	ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO MAGNIF									TENSILE TEST RESULTS		
P1706 A	1.56	2.864	0.000	0.122	0.178	0.747	0.430	0.297	0.545	37.1	15.8	5.2
P1706 B	1.60	2.824	-0.009	0.117	0.177	0.783	0.414	0.319	0.567	37.1	15.8	5.2
P1707 A	1.65	2.826	-0.009	0.000	0.000	0.768	0.382	0.311	0.584	38.8	17.6	7.0
P1707 B	1.63	2.879	0.000	0.000	0.000	0.802	0.386	0.302	0.566	38.8	17.6	7.0
P1717 A	1.54	2.824	0.004	0.099	0.195	0.790	0.439	0.421	0.545	37.2	16.0	5.9
P1717 B	1.61	2.817	0.000	0.131	0.195	0.770	0.440	0.422	0.571	37.2	16.0	5.9
P1718 A	1.66	2.881	0.003	0.132	0.194	0.750	0.427	0.406	0.576	36.8	14.5	6.0
P1718 B	1.59	2.861	0.000	0.129	0.198	0.793	0.437	0.426	0.556	36.8	14.5	6.0
P1719 A	1.63	2.859	0.000	0.000	0.000	0.776	0.455	0.416	0.570	38.4	17.5	9.8
P1719 B	1.66	2.839	0.000	0.000	0.000	0.807	0.440	0.458	0.585	38.4	17.5	9.8
P1720 A	1.66	2.834	-0.007	0.000	0.000	0.794	0.452	0.427	0.586	39.8	15.3	10.7
P1720 B	1.63	2.848	0.000	0.000	0.000	0.794	0.453	0.449	0.572	39.8	15.3	10.7
P1810 A	1.62	2.856	-0.117	0.000	0.000	0.854	0.438	0.312	0.567	36.5	0.0	5.9
P1810 B	1.56	2.843	-0.128	0.025	0.000	0.784	0.457	0.352	0.549	36.5	0.0	5.9
P1815 A	1.57	2.845	-0.116	-0.007	0.011	0.851	0.457	0.369	0.552	37.1	16.3	5.7
P1815 B	1.65	2.826	-0.115	0.000	0.000	0.899	0.478	0.315	0.584	37.1	16.3	5.7
P1816 A	1.60	2.900	-0.129	-0.014	0.000	0.828	0.500	0.338	0.552	34.5	14.5	6.0
P1816 B	1.62	2.854	-0.142	-0.007	-0.004	0.876	0.547	0.340	0.568	34.5	14.5	6.0
P1818 A	1.98	3.396	-0.110	0.097	0.221	0.716	0.506	0.389	0.583	28.5	15.3	2.6
P1818 B	1.92	3.383	-0.109	0.115	0.204	0.730	0.532	0.349	0.568	28.5	15.3	2.6
P1819 A	2.03	3.405	-0.112	0.109	0.220	0.734	0.499	0.347	0.598	28.6	19.0	2.2
P1819 B	1.91	3.353	-0.101	0.119	0.194	0.790	0.507	0.328	0.570	28.6	19.0	2.2
P1820 A	1.92	3.394	-0.106	0.115	0.206	0.787	0.510	0.351	0.566	28.2	17.5	2.3
P1820 B	1.87	3.394	-0.103	0.115	0.200	0.757	0.527	0.357	0.551	28.2	17.5	2.3
P1908 A	1.57	2.905	0.014	0.141	0.182	0.795	0.423	0.361	0.540	35.7	17.1	3.8
P1908 B	1.62	2.838	-0.009	0.137	0.187	0.817	0.486	0.391	0.571	35.7	17.1	3.8
P1909 A	1.53	2.867	-0.007	0.000	0.000	0.767	0.419	0.356	0.534	39.2	13.9	10.3
P1909 B	1.53	2.827	-0.007	0.000	0.000	0.835	0.439	0.371	0.541	39.2	13.9	10.3
P1910 A	1.56	2.818	0.000	0.138	0.188	0.798	0.461	0.337	0.554	37.3	16.7	5.5
P1910 B	1.55	2.831	-0.002	0.145	0.162	0.773	0.427	0.420	0.547	37.3	16.7	5.5
P1911 A	1.57	2.830	-0.007	0.000	0.000	0.785	0.424	0.357	0.555	39.6	15.9	10.8
P1911 B	1.54	2.850	-0.009	0.000	0.000	0.793	0.439	0.379	0.540	39.6	15.9	10.8

Table 3.3

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PHOTO IDENT: 2 PIX PER SAMPLE	CRN/ROOT INTERSEC WIDTH	ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO MAGNIF								TENSILE TEST RESULTS		
		PHOTO MAG.	MISMATCH	WELD REINFORCEM CROWN	WELD REINFORCEM ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	ROWN/ROC INTERSECT WIDTH	UTS (ksi)	.2% Y.S. (ksi)	% Elong
P1912 A	1.62	2.876	0.003	0.136	0.184	0.817	0.452	0.389	0.563	37.0	16.1	5.4
P1912 B	1.59	2.850	0.007	0.137	0.168	0.842	0.435	0.390	0.558	37.0	16.1	5.4
P1913 A	1.61	2.840	-0.012	0.000	0.000	0.838	0.423	0.384	0.567	39.6	15.4	11.0
P1913 B	1.61	2.880	0.002	0.000	0.000	0.823	0.424	0.340	0.559	39.6	15.4	11.0
P2105 A	1.69	2.847	-0.002	0.000	0.000	0.717	0.365	0.155	0.594	39.9	19.5	8.7
P2105 B	1.62	2.860	0.002	0.000	0.000	0.685	0.462	0.164	0.566	39.9	19.5	8.7
P2106 A	2.03	3.415	-0.022	0.114	0.152	0.668	0.428	0.173	0.594	36.7	18.4	3.7
P2106 B	2.07	3.369	-0.003	0.122	0.169	0.686	0.496	0.181	0.614	36.7	18.4	3.7
P2107 A	1.89	2.847	-0.004	0.000	0.000	0.724	0.407	0.186	0.664	39.9	18.8	9.0
P2107 B	1.76	2.880	0.000	0.000	0.000	0.688	0.410	0.188	0.611	39.9	18.8	9.0
P2108 A	2.01	3.369	-0.019	0.110	0.175	0.683	0.736	0.187	0.597	37.6	20.3	3.5
P2108 B	1.96	3.342	0.001	0.123	0.177	0.703	0.485	0.180	0.586	37.6	20.3	3.5
P2109 A	1.80	2.827	0.000	0.000	0.000	0.828	0.432	0.202	0.637	38.7	17.6	9.0
P2109 B	1.74	2.867	0.000	0.000	0.000	0.610	0.391	0.192	0.607	38.7	17.6	9.0
P2110 A	2.03	3.322	0.000	0.126	0.147	0.743	0.436	0.172	0.611	35.6	14.6	4.0
P2110 B	1.95	3.369	0.007	0.113	0.178	0.680	0.754	0.178	0.579	35.6	14.6	4.0
P2207 A	1.58	2.785	-0.147	0.000	0.000	0.574	0.478	0.154	0.567	36.8	14.0	6.9
P2207 B	1.65	2.865	-0.138	0.000	0.000	0.586	0.510	0.161	0.576	36.8	14.0	6.9
P2208 A	1.94	3.404	-0.131	0.085	0.179	0.617	0.520	0.176	0.570	27.4	14.3	3.3
P2208 B	1.86	3.397	-0.113	0.082	0.185	0.618	0.515	0.203	0.548	27.4	14.3	3.3
P2209 A	1.67	2.814	-0.119	0.000	0.000	0.594	0.476	0.188	0.594	38.0	15.8	7.9
P2209 B	1.70	2.906	-0.127	0.000	0.000	0.585	0.502	0.193	0.585	38.0	15.8	7.9
P2210 A	1.93	3.362	-0.113	0.080	0.164	0.619	0.506	0.193	0.574	27.9	16.2	2.8
P2210 B	1.84	3.388	-0.115	0.086	0.162	0.637	0.502	0.180	0.543	27.9	16.2	2.8
P2211 A	1.67	2.805	-0.135	0.000	0.000	0.595	0.520	0.193	0.595	38.0	17.7	7.5
P2211 B	1.83	2.825	-0.113	0.000	0.000	0.644	0.520	0.166	0.648	38.0	17.7	7.5
P2212 A	1.97	3.393	-0.137	0.088	0.177	0.631	0.522	0.200	0.581	27.7	15.9	4.0
P2212 B	1.96	3.386	-0.102	0.083	0.183	0.620	0.520	0.192	0.579	27.7	15.9	4.0
P2310 A	1.76	2.856	0.012	0.130	0.189	0.623	0.452	0.175	0.616	35.2	16.4	3.7
P2310 B	1.60	2.830	0.014	0.106	0.187	0.615	0.449	0.194	0.565	35.2	16.4	3.7
P2311 A	1.66	2.898	0.002	0.000	0.000	0.701	0.456	0.190	0.573	40.7	19.7	8.0
P2311 B	1.69	2.845	0.002	0.000	0.000	0.745	0.443	0.190	0.594	40.7	19.7	8.0

Table 3.3

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PHOTO IDENT: 2 PIX PER SAMPLE	CRN/ROOT INTERSEC WIDTH	ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO MAGNIF: PHOTO MAG.	MISMATCH	WELD REINFORCEM: CROWN	WELD REINFORCEM: ROOT	WELD WIDTH: CROWN	WELD WIDTH: ROOT	CROWN DEPTH	ROWN/ROC INTERSECT WIDTH	TENSILE TEST RESULTS: UTS (ksi)	.2% Y.S. (ksi)	% Elong
P2312 A	1.82	2.856	0.011	0.105	0.179	0.669	0.490	0.186	0.637	35.7	18.9	3.5
P2312 B	1.68	2.830	0.011	0.106	0.198	0.654	0.477	0.201	0.594	35.7	18.9	3.5
P2313 A	1.57	2.853	-0.007	0.000	0.000	0.676	0.382	0.186	0.550	40.1	18.9	9.4
P2313 B	1.70	2.873	0.000	0.000	0.000	0.707	0.414	0.205	0.592	40.1	18.9	9.4
P2314 A	1.63	2.817	0.012	0.124	0.195	0.653	0.479	0.177	0.579	34.4	14.1	2.3
P2314 B	1.62	2.824	0.012	0.110	0.198	0.634	0.457	0.195	0.574	34.4	14.1	2.3
P2315 A	1.69	2.801	0.009	0.000	0.000	0.635	0.411	0.218	0.603	41.0	19.1	7.8
P2315 B	1.70	2.834	0.018	0.000	0.000	0.649	0.469	0.212	0.600	41.0	19.1	7.8
T5708 A	N/A	2.867	-0.005	0.000	0.000	0.412	0.419	N/A	N/A	42.0	20.8	6.8
T5708 B	N/A	2.840	0.009	0.000	0.000	0.433	0.387	N/A	N/A	42.0	20.8	6.8
T5709 A	N/A	3.423	-0.004	0.088	0.076	0.467	0.426	N/A	N/A	44.5	21.6	7.1
T5709 B	N/A	3.417	-0.010	0.082	0.076	0.439	0.468	N/A	N/A	44.5	21.6	7.1
T5710 A	N/A	2.835	0.000	0.000	0.000	0.423	0.451	N/A	N/A	42.6	19.9	7.3
T5710 B	N/A	2.868	0.014	0.000	0.000	0.425	0.429	N/A	N/A	42.6	19.9	7.3
T5711 A	N/A	3.426	0.001	0.073	0.088	0.476	0.438	N/A	N/A	44.4	25.1	7.0
T5711 B	N/A	3.399	0.003	0.076	0.074	0.474	0.468	N/A	N/A	44.4	25.1	7.0
T5712 A	N/A	2.820	0.000	0.000	0.000	0.433	0.440	N/A	N/A	41.9	20.1	7.3
T5712 B	N/A	2.840	0.005	0.000	0.000	0.444	0.430	N/A	N/A	41.9	20.1	7.3
T5713 A	N/A	3.368	-0.004	0.083	0.080	0.475	0.460	N/A	N/A	44.5	24.2	6.9
T5713 B	N/A	3.415	-0.001	0.085	0.082	0.551	0.474	N/A	N/A	44.5	24.2	6.9
T5812 A	N/A	2.820	-0.112	0.069	0.117	0.461	0.457	N/A	N/A	37.2	21.2	4.2
T5812 B	N/A	2.880	-0.115	0.090	0.080	0.451	0.434	N/A	N/A	37.2	21.2	4.2
T5813 A	N/A	2.873	-0.122	0.000	0.000	0.470	0.456	N/A	N/A	40.1	19.9	6.0
T5813 B	N/A	2.867	-0.119	0.000	0.000	0.443	0.398	N/A	N/A	40.1	19.9	6.0
T5814 A	N/A	2.860	-0.114	0.087	0.087	0.441	0.465	N/A	N/A	36.6	23.5	4.2
T5814 B	N/A	2.853	-0.112	0.081	0.081	0.449	0.449	N/A	N/A	36.6	23.5	4.2
T5815 A	N/A	2.826	-0.154	0.000	0.000	0.465	0.446	N/A	N/A	37.8	18.3	5.7
T5815 B	N/A	2.832	-0.124	0.000	0.000	0.431	0.410	N/A	N/A	37.8	18.3	5.7
T5816 A	N/A	2.869	-0.099	0.091	0.091	0.453	0.467	N/A	N/A	36.9	24.1	3.9
T5816 B	N/A	2.882	-0.108	0.083	0.083	0.458	0.475	N/A	N/A	36.9	24.1	3.9
T5817 A	N/A	2.877	-0.108	0.000	0.000	0.441	0.424	N/A	N/A	41.2	22.4	5.7
T5817 B	N/A	2.857	-0.096	0.000	0.000	0.469	0.490	N/A	N/A	41.2	22.4	5.7

average uts for VPPA welds	38.1
std of uts for vppa welds	4.0
highest uts for vppa welds	41.0
lowest uts for vppa welds	27.4
average uts for gta welds	39.1
std of uts for gta welds	5.5
highest uts for gta welds	45.2
lowest uts for gta welds	25.3

Table 3.3

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PHOTO IDENT: 2 PIX PER SAMPLE	CRN/ROOT INTERSEC WIDTH	PHOTO MAG.	MISMATCH	WELD REINFORCEM CROWN	WELD REINFORCEM ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	ROWN/ROC INTERSECT WIDTH	UTS (ksi)	.2% Y.S. (ksi)	% Elong
	ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO MAGNIF									TENSILE TEST RESULTS		
T5910 A	N/A	2.846	-0.014	0.000	0.000	0.499	0.260	N/A	N/A	34.2	26.8	4.8
T5910 B	N/A	2.833	-0.026	0.000	0.000	0.484	0.226	N/A	N/A	34.2	26.8	4.8
T5911 A	N/A	2.857	-0.005	0.063	0.032	0.504	0.235	N/A	N/A	25.3	2.8	2.6
T5911 B	N/A	2.851	-0.007	0.063	0.032	0.509	0.242	N/A	N/A	25.3	2.8	2.6
T5912 A	N/A	2.872	-0.007	0.000	0.000	0.456	0.212	N/A	N/A	36.4	27.1	5.2
T5912 B	N/A	2.859	-0.009	0.000	0.000	0.462	0.192	N/A	N/A	36.4	27.1	5.2
T5913 A	N/A	2.846	-0.007	0.060	0.035	0.534	0.239	N/A	N/A	25.5	0.0	3.1
T5913 B	N/A	2.859	0.000	0.056	0.031	0.514	0.241	N/A	N/A	25.5	0.0	3.1
T5914 A	N/A	2.846	-0.004	0.000	0.000	0.467	0.225	N/A	N/A	37.7	0.0	4.6
T5914 B	N/A	2.820	0.004	0.000	0.000	0.496	0.248	N/A	N/A	37.7	0.0	4.6
T5915 A	N/A	2.861	-0.002	0.056	0.024	0.510	0.255	N/A	N/A	27.7	18.3	3.3
T5915 B	N/A	2.835	0.004	0.032	0.021	0.529	0.226	N/A	N/A	27.7	18.3	3.3
T6108 A	N/A	2.859	-0.005	0.073	0.077	0.367	0.437	N/A	N/A	44.3	22.7	6.5
T6108 B	N/A	2.846	0.002	0.074	0.074	0.397	0.415	N/A	N/A	44.3	22.7	6.5
T6109 A	N/A	2.832	0.000	0.000	0.000	0.321	0.371	N/A	N/A	43.4	19.4	7.4
T6109 B	N/A	2.846	0.000	0.000	0.000	0.313	0.358	N/A	N/A	43.4	19.4	7.4
T6110 A	N/A	2.852	-0.005	0.074	0.088	0.403	0.442	N/A	N/A	44.9	22.0	2.3
T6110 B	N/A	2.879	-0.003	0.080	0.080	0.399	0.399	N/A	N/A	44.9	22.0	2.3
T6111 A	N/A	2.841	0.000	0.000	0.000	0.366	0.377	N/A	N/A	45.1	21.8	6.8
T6111 B	N/A	2.868	0.005	0.000	0.000	0.335	0.363	N/A	N/A	45.1	21.8	6.8
T6112 A	N/A	2.859	0.000	0.077	0.080	0.378	0.388	N/A	N/A	45.2	23.0	7.0
T6112 B	N/A	2.879	0.000	0.076	0.076	0.420	0.445	N/A	N/A	45.2	23.0	7.0
T6113 A	N/A	2.814	0.000	0.007	0.000	0.370	0.370	N/A	N/A	43.4	19.9	6.0
T6113 B	N/A	2.828	-0.004	0.000	0.000	0.336	0.393	N/A	N/A	43.4	19.9	6.0
T6209 A	N/A	2.867	-0.098	0.052	0.042	0.349	0.394	N/A	N/A	40.7	22.5	5.3
T6209 B	N/A	2.873	-0.092	0.066	0.049	0.414	0.383	N/A	N/A	40.7	22.5	5.3
T6210 A	N/A	2.781	-0.106	0.000	0.000	0.370	0.316	N/A	N/A	40.4	21.3	6.0
T6210 B	N/A	2.853	-0.116	0.000	0.000	0.329	0.340	N/A	N/A	40.4	21.3	6.0
T6211 A	N/A	2.853	-0.066	0.077	0.056	0.435	0.400	N/A	N/A	41.0	20.1	5.3
T6211 B	N/A	2.847	-0.095	0.060	0.053	0.372	0.376	N/A	N/A	41.0	20.1	5.3
T6212 A	N/A	2.886	-0.104	0.000	0.000	0.340	0.319	N/A	N/A	42.5	22.3	6.0
T6212 B	N/A	2.853	-0.102	0.000	0.000	0.466	0.361	N/A	N/A	42.5	22.3	6.0
T6213 A	N/A	2.840	-0.090	0.063	0.056	0.373	0.366	N/A	N/A	41.0	22.0	4.6

Table 3.3

GEOMET
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PHOTO IDENT: 2 PIX PER SAMPLE	CRN/ROOT INTERSEC WIDTH	ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO MAGNIF PHOTO MAG.	MISMATCH	WELD REINFORCEM CROWN	ROOT	WELD WIDTH CROWN	ROOT	CROWN DEPTH	ROWN/ROC INTERSECT WIDTH	TENSILE TEST RESULTS UTS (ksi)	.2% Y.S. (ksi)	% Elong
T6213 B	N/A	2.847	-0.090	0.056	0.046	0.386	0.369	N/A	N/A	41.0	22.0	4.6
T6214 A	N/A	2.856	-0.102	0.000	0.000	0.357	0.322	N/A	N/A	41.6	19.8	5.5
T6214 B	N/A	2.856	-0.096	0.000	0.000	0.340	0.329	N/A	N/A	41.6	19.8	5.5
T6314 A	N/A	2.914	-0.010	0.000	0.000	0.408	0.237	N/A	N/A	41.5	0.0	5.2
T6314 B	N/A	2.834	0.004	0.000	0.000	0.423	0.243	N/A	N/A	41.5	0.0	5.2
T6315 A	N/A	2.878	-0.002	0.045	0.038	0.389	0.281	N/A	N/A	29.0	17.1	5.0
T6315 B	N/A	2.845	-0.002	0.063	0.032	0.411	0.271	N/A	N/A	29.0	17.1	5.0
T6316 A	N/A	2.871	-0.005	0.000	0.000	0.390	0.258	N/A	N/A	41.1	0.0	5.3
T6316 B	N/A	2.818	0.007	0.000	0.000	0.369	0.263	N/A	N/A	41.1	0.0	5.3
T6317 A	N/A	2.876	-0.005	0.063	0.031	0.396	0.268	N/A	N/A	31.3	21.2	4.2
T6317 B	N/A	2.850	0.002	0.060	0.032	0.407	0.274	N/A	N/A	31.3	21.2	4.2
T6318 A	N/A	2.816	-0.012	0.000	0.000	0.394	0.273	N/A	N/A	41.5	0.0	6.1
T6318 B	N/A	2.863	0.005	0.000	0.000	0.402	0.265	N/A	N/A	41.5	0.0	6.1
T6319 A	N/A	2.863	0.000	0.059	0.031	0.402	0.283	N/A	N/A	32.6	0.0	3.4
T6319 B	N/A	2.836	0.004	0.053	0.028	0.409	0.303	N/A	N/A	32.6	0.0	3.4

average uts for gta welds	39.1
std of uts for gta welds	5.5
highest uts for gta welds	45.2
lowest uts for gta welds	25.3

Table 3.3

Due to a work overload at NASA, NASA personnel were unable to apply the photo-resist grid pattern on some aluminum specimens as planned. Six specimens (a shaved and unshaved of a normal, mismatched, and a peaked weld) have been machined and etched. As an alternative to the photo-resist, NRC scribed grid patterns onto these specimens.

Six tensile specimens of 2219-T87 aluminum were scribed to form a grid pattern on the weld cross-section. The two specimens (one shaved, one unshaved) with parallel sides and no peaking or mismatch were tensile tested. Vickers hardness measurements were made on these two welds prior to tensile testing - they consistently had hardnesses of 82-95 near the weld centerline, increasing to 100-112 near the weld edges, dropping to 83-89 in the weld adjacent to the fusion line, and increasing to >110 going through the HAZ and into the parent metal. This is consistent with previous measurements of other 2219-T87 welds. The grids on these welds were photographed before and after tensile testing. The grids were measured for the shaved specimen to determine the strains that occurred throughout the weld during tensile testing.

Evaluations were made of the strain measurements obtained from grids on aluminum tensile specimens. Both evaluators (Steve Gordon and Jim Favenesi of NRC) agreed that the results were not of any use for the current theory development effort. This technique had two problems: it was very time consuming, and it was relatively inaccurate (before and after measurements were made by hand). If more accurate measurements were made automatically using computerized image analysis for example, both these problems could be solved and it might then prove worthwhile. For this project, however, this technique is not planned to be pursued further.

4.0 Statistical Evaluation Of Expanded Database

A limited amount of aluminum-lithium weld geometry and associated tensile test data was provided to NRC by NASA. An initial analysis of the data was made seeking geometric correlations to UTS variations. Although there was a lot of scatter in this data, trends were observed in which UTS decreased with increasing amounts of peaking, and to a lesser degree with increasing amounts of mismatch. Conclusive interpretation proved difficult due to the limited number of samples, many of which had significant amounts of both peaking and mismatch which complicates the determination of the effects of each on UTS. This data, along with other NASA provided aluminum-lithium data for welds with relatively low amounts of peaking and mismatch, will be retained for further analysis with the model theory. Table 4.1 and 4.2 have graphs showing UTS as a function of peaking and mismatch for 0.200" 2195 Al-Li.

Comparisons of theory predictions to test data were made for welds with essentially parallel fusion lines and no reinforcements, mismatch or peaking. These comparisons were made with 0.25" thick 2219-T87. The results of these comparisons are located in table 4.3 and its associated graph.

Statistical analysis was done on the data for 0.75" 2219-T87 aluminum. This analysis will seek correlations of geometric features to tensile test properties. The data relating peaking and mismatch to UTS are located in tables 4.4 and 4.5.

Panel #	Avg UTS	Avg UTS for 7 pts	Avg % Elong	Avg Pking	deg.	deg.	mins	mins	Avg MM	mm1	mm2	MM related angle	UTS based on linear regression calc. for peaking	for mismatch	avg of two	Differences between UTS and predicted based on peaking	mismatch	avg of two
28	48		2.5	0.5	0	0	48	6	0.060	54	66	16.7	49.6	47.8	48.7	-1.6	0.2	-0.7
12	51		2.6	0.6	0	0	34	34	0.013	13	13	3.7	49.2	47.9	48.6	2.1	3.4	2.7
21	44		2.2	0.7	0	0	44	44	0.020	20	20	5.7	48.7	47.9	48.3	-4.3	-3.5	-3.9
24	46		3.1	1.1	1	1	5	5	0.017	17	17	4.9	47.5	47.9	47.7	-1.3	-1.7	-1.5
10	51		2.6	1.1	0	1	15	56	0.015	1	29	4.3	47.4	47.9	47.7	3.5	3.0	3.2
18	43		2.3	1.3	1	1	19	19	0.039	39	39	11.0	46.7	47.8	47.3	-3.3	-4.4	-3.9
27	52	48.029	2.6	1.4	1	1	25	25	0.024	24	24	6.8	46.3	47.9	47.1	5.7	4.1	4.9
9	41		1.8	2.2	2	1	34	46	0.004	7	1	1.1	43.8	48.0	45.9	-3.0	-7.2	-5.1
6	42		1.7	2.6	1	3	46	26	0.026	25	27	7.4	42.3	47.9	45.1	-0.4	-6.0	-3.2
8	42		--------	2.7	2	2	34	51	0.016	12	20	4.6	42.0	47.9	44.9	-0.5	-6.4	-3.4
7	42		1.9	2.8	2	3	24	8	0.040	38	42	11.3	41.8	47.8	44.8	-0.1	-6.2	-3.2
1	41		2.2	2.9	2	3	17	26	0.037	25	48	10.3	41.5	47.9	44.7	-0.8	-7.2	-4.0
3	34		1.1	3.0	2	2	58	58	0.043	43	43	12.1	41.1	47.8	44.5	-7.1	-13.8	-10.5
4	44	40.657	2.5	3.1	2	3	58	12	0.017	10	24	4.9	40.7	47.9	44.3	3.4	-3.9	-0.3
11	51		--------	3.3	3	2	39	51	0.006	10	1	1.6	40.1	48.0	44.0	10.5	2.6	6.6
5	40		--------	3.3	3	3	19	22	0.016	20	12	4.6	39.8	47.9	43.9	0.6	-7.5	-3.4
2	33		--------	4.0	3	4	49	7	0.050	52	48	14.0	37.7	47.8	42.8	-5.1	-15.2	-10.2
15	33		--------	5.5	5	5	52	11	0.062	83	41	17.2	32.4	47.8	40.1	0.9	-14.4	-6.7
39	36		1.2	5.7	6	4	47	34	0.013	12	14	3.7	31.9	47.9	39.9	3.6	-12.4	-4.4
13	33		--------	5.8	6	5	23	15	0.094	95	92	25.1	31.4	47.7	39.5	1.7	-14.5	-6.4
14	22	35.393	--------	7.2	7	7	10	17	0.094	85	103	25.2	26.7	47.7	37.2	-4.6	-25.6	-15.1
Maximums:				7.225					0.094									
Minimums:				0.45					0.004									

PEAK Regression Output:	
Constant	51.139553
Std Err of Y Est	4.14505542
R Squared	0.71521278
No. of Observations	21
Degrees of Freedom	19
X Coefficier	-3.388653
Std Err of C	0.4905609

MISMATCH Regression Output:	
Constant	47.961023
Std Err of Y Est	5.7066404
R Squared	0.460215
No. of Observations	21
Degrees of Freedom	19
X Coefficient(s)	-197.3761
Std Err of Coef.	49.039709

Table 4.1

UTS as a function of Peaking
0.200" thick Al-Li

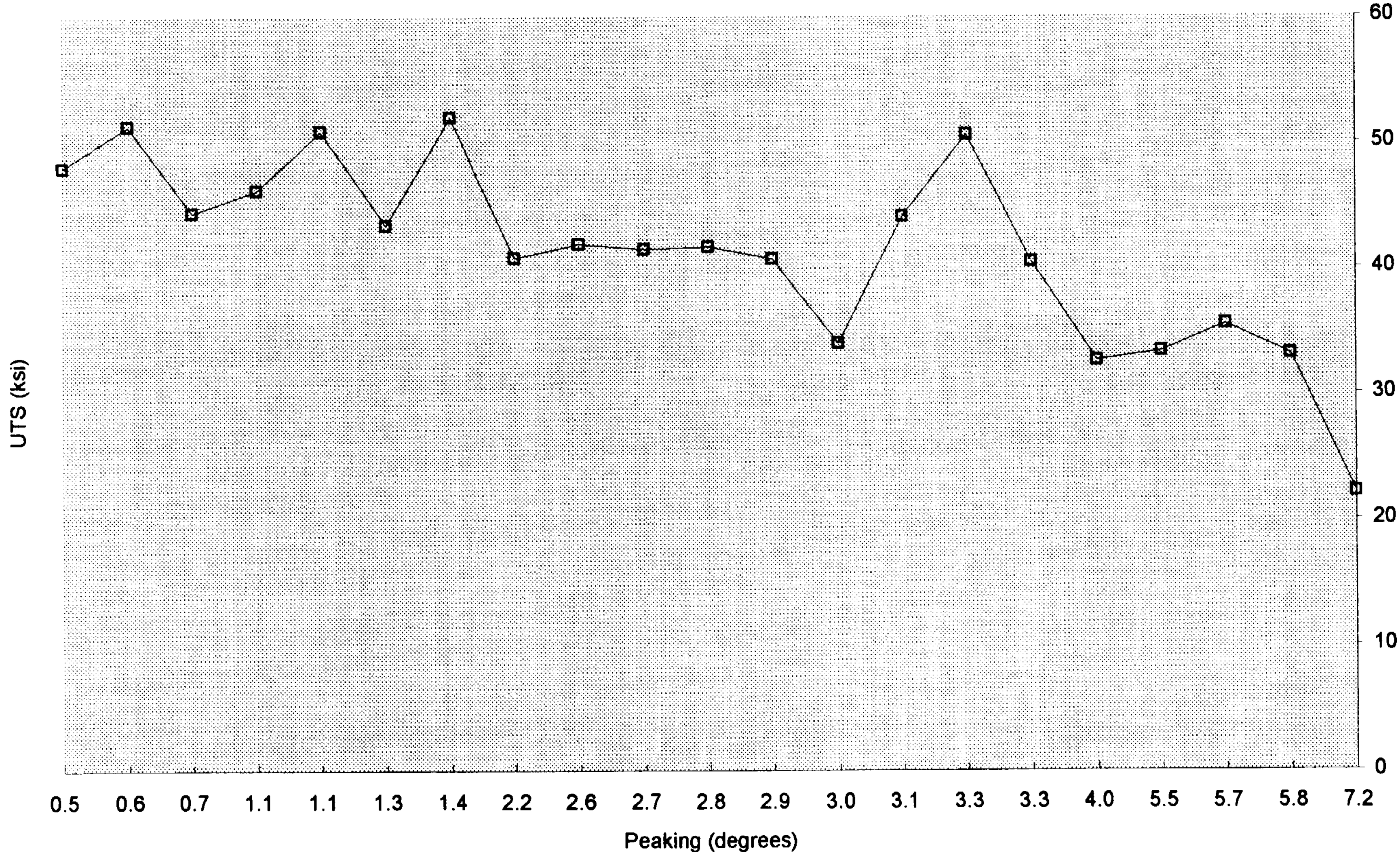

Table 4.1 Graph

Panel	Avg UTS	Avg UTS for 7 pts	Avg % Elong	Avg Pking	degr.	degr.	mins	mins	Avg MM	MM (mils)	mm1	mm2	MM related angle	UTS based on linear regression calcu: for peaking	for mismatch	avg of two	Differences between UTS and predicted based on... peaking	mismatch	average of two
9	40.8		1.8	2.2	2	1	34.0	46	0.004	4.0	7.0	1.0	1.1	43.8	48.0	45.9	-3.0	-7.2	-5.1
11	50.6		*******	3.3	3	2	39.0	51	0.006	5.5	10.0	1.0	1.6	40.1	48.0	44.0	10.5	2.6	6.6
12	51.3		2.6	0.6	0	0	34.0	34	0.013	13.0	13.0	13.0	3.7	49.2	47.9	48.6	2.1	3.4	2.7
39	35.5		1.2	5.7	6	4	47.0	34	0.013	13.0	12.0	14.0	3.7	31.9	47.9	39.9	3.6	-12.4	-4.4
10	50.9		2.6	1.1	0	1	15.0	56	0.015	15.0	1.0	29.0	4.3	47.4	47.9	47.7	3.5	3.0	3.2
5	40.5		*******	3.3	3	3	19.0	22	0.016	16.0	20.0	12.0	4.6	39.8	47.9	43.9	0.6	-7.5	-3.4
8	41.5	44.4	*******	2.7	2	2	34.0	51	0.016	16.0	12.0	20.0	4.6	42.0	47.9	44.9	-0.5	-6.4	-3.4
24	46.2		3.1	1.1	1	1	5.0	5	0.017	17.0	17.0	17.0	4.9	47.5	47.9	47.7	-1.3	-1.7	-1.5
4	44.1		2.5	3.1	2	3	58.0	12	0.017	17.0	10.0	24.0	4.9	40.7	47.9	44.3	3.4	-3.9	-0.3
21	44.4		2.2	0.7	0	0	44.0	44	0.020	20.0	20.0	20.0	5.7	48.7	47.9	48.3	-4.3	-3.5	-3.9
27	52.0		2.6	1.4	1	1	25.0	25	0.024	24.0	24.0	24.0	6.8	46.3	47.9	47.1	5.7	4.1	4.9
6	41.9		1.7	2.6	1	3	46.0	26	0.026	26.0	25.0	27.0	7.4	42.3	47.9	45.1	-0.4	-6.0	-3.2
1	40.7		2.2	2.9	2	3	17.0	26	0.037	36.5	25.0	48.0	10.3	41.5	47.9	44.7	-0.8	-7.2	-4.0
18	43.4	44.7	2.3	1.3	1	1	19.0	19	0.039	39.0	39.0	39.0	11.0	46.7	47.8	47.3	-3.3	-4.4	-3.9
7	41.7		1.9	2.8	2	3	24.0	8	0.040	40.0	38.0	42.0	11.3	41.8	47.8	44.8	-0.1	-6.2	-3.2
3	34.0		1.1	3.0	2	2	58.0	58	0.043	43.0	43.0	43.0	12.1	41.1	47.8	44.5	-7.1	-13.8	-10.5
2	32.6		*******	4.0	3	4	49.0	7	0.050	50.0	52.0	48.0	14.0	37.7	47.8	42.8	-5.1	-15.2	-10.2
28	48.0		2.5	0.5	0	0	48.0	6	0.060	60.0	54.0	66.0	16.7	49.6	47.8	48.7	-1.6	0.2	-0.7
15	33.4		*******	5.5	5	5	52.0	11	0.062	62.0	83.0	41.0	17.2	32.4	47.8	40.1	0.9	-14.4	-6.7
13	33.2		*******	5.8	6	5	23.0	15	0.094	93.5	95.0	92.0	25.1	31.4	47.7	39.5	1.7	-14.5	-6.4
14	22.1	35.0	*******	7.2	7	7	10.0	17	0.094	94.0	85.0	103.0	25.2	26.7	47.7	37.2	-4.6	-25.6	-15.1
	Maximums:			7.225					0.094										
	Minimums:			0.45					0.004										

PEAKIN Regression Output:

Constant	51.139553
Std Err of Y Est	4.1450554
R Squared	0.7152128
No. of Observations	21
Degrees of Freedom	19
X Coefficient(s)	-3.389
Std Err of Coef.	0.491

MISMATCH

Constant	47.98102317
Std Err of Y Est	5.706640419
R Squared	0.460214971
No. of Observatio	21
Degrees of Freec	19
X Coefficient(s)	
Std Err of Coef.	

Table 4.2

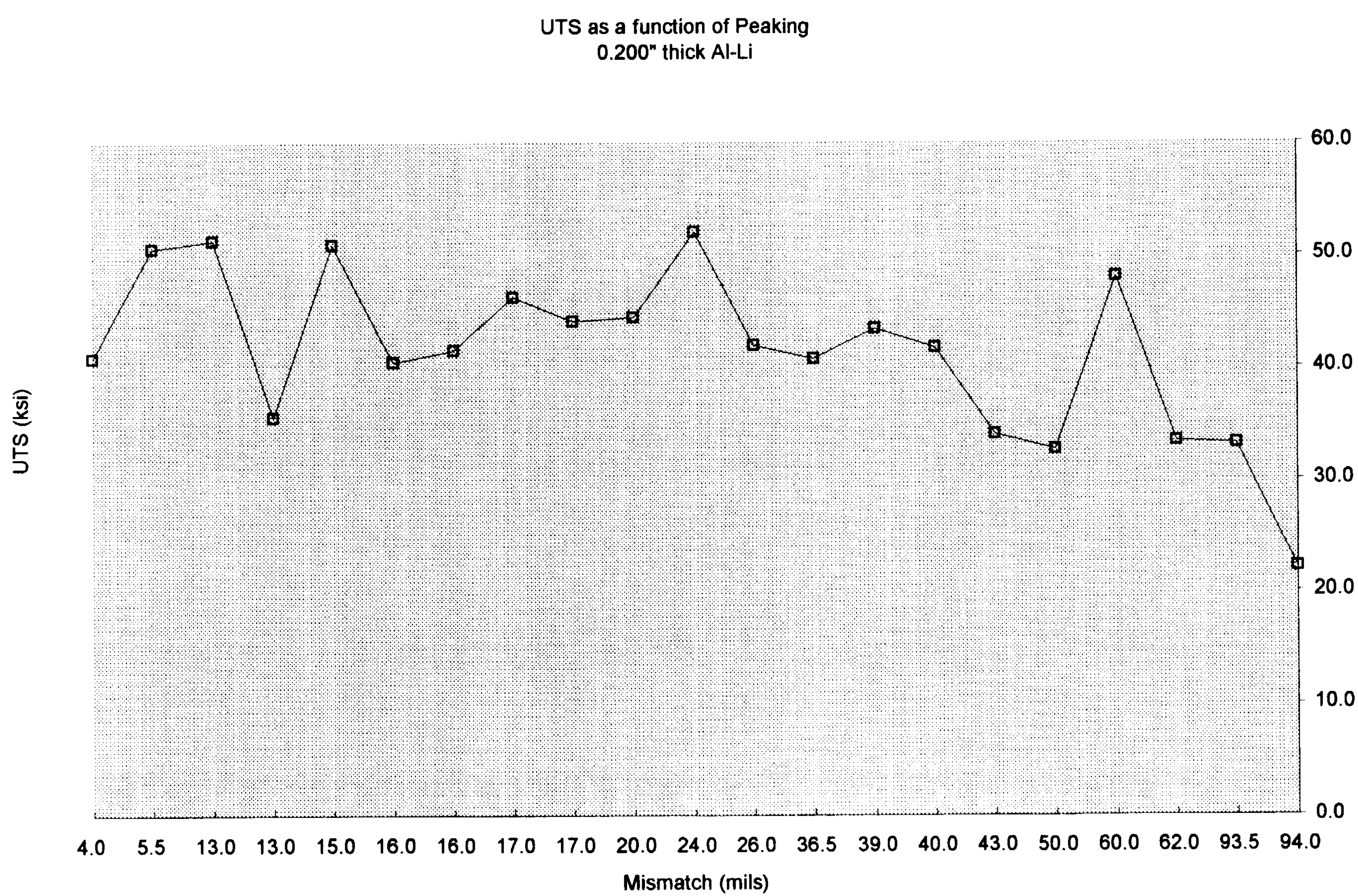

Table 4.2 Graph

LINE DATA

		PRD	PRD-FL	ACT	Y.S.
1/4" AL VPPAW	MEAN=	39.41	37.07	38.16	22.11
	MAX=	43.95	41.67	47.80	28.30
	MIN=	24.71	21.65	27.00	15.40
	STD=	4.81	5.92	4.91	3.29
1/4" AL GTAW	MEAN=	42.38	38.28	39.20	25.45
	MAX=	48.00	41.63	44.60	29.10
	MIN=	28.96	28.32	27.90	18.30
	STD=	4.09	3.28	4.01	3.41

		SHAVED ACT	SHAVED PRD	UNSHAVEI ACT	UNSHAVEI PRD
1/4" AL VPPAW & GTAW	MEAN=	38.60	40.35	38.75	41.42
	MAX=	43.40	47.36	47.80	48.00
	MIN=	33.00	24.71	27.00	28.96
	STD=	2.31	5.26	6.00	4.00

Table 4.3

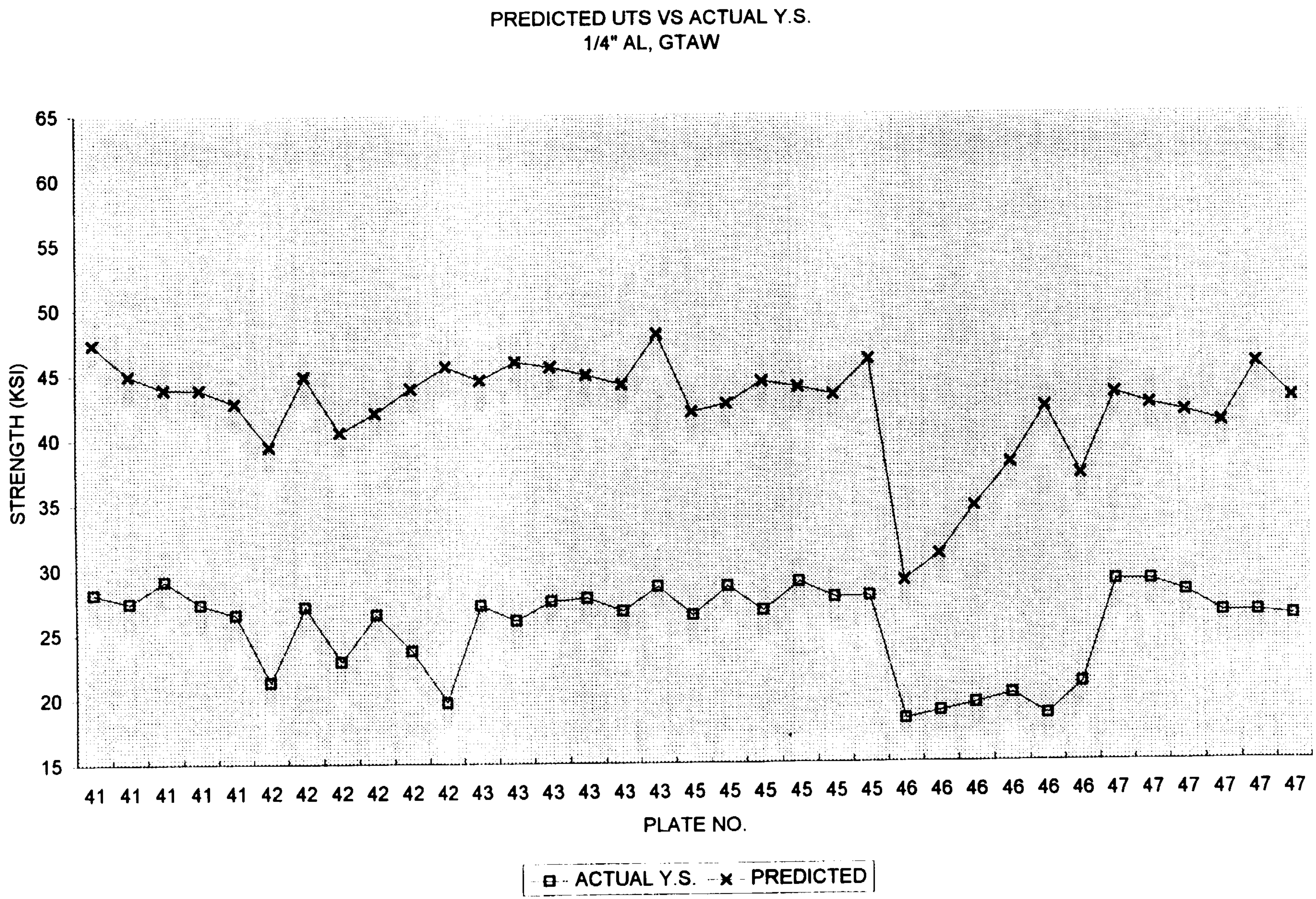

Table 4.3 Graph

GEOMETRY EFFECTS - GEOMETRY MEASUREMENTS AND TENSILE TEST RESULTS (5-13-94)
FILE C:\GEOM-FX\peaking.WK1

PHOTO IDENT: 2 PIX PER SAMPLE	MTRI	THICK	SHAV	PLATE THICKNES A	PLATE THICKNES B	MEASUREMENTS FROM MACROPHOTOGRAPHS: PLATE THICKN A	PLATE THICKN B	PEAKING	MISMATC	WELD REINFORC CROWN	WELD REINFORC ROOT	WELD WIDT CROWN	WELD WIDT ROOT	FUSION LINE ANGLES 1/5	2/6	3/7	4/8	CROW DEPT	CRN/ROOT INTERSEC WIDTH	ACTUAL PHOTO MAG.
T6319 A	ALUM	0.75	No	0.753	0.756	2.16	2.16	-9.25										N/A	N/A	2.863
T6319 B	ALUM	0.75	No	0.753	0.756	2.14	2.14	-9.00										N/A	N/A	2.836
T6317 A	ALUM	0.75	No	0.753	0.756	2.15	2.19	-9.50										N/A	N/A	2.876
T6317 B	ALUM	0.75	No	0.753	0.756	2.14	2.16	-9.25										N/A	N/A	2.850
T6315 B	ALUM	0.75	No	0.753	0.755	2.13	2.16	-9.50										N/A	N/A	2.845
T6315 A	ALUM	0.75	No	0.753	0.755	2.17	2.17	-9.25										N/A	N/A	2.878
T6213 B	ALUM	0.75	No	0.755	0.759	2.15	2.16	1.00	-0.255	0.16	0.13	1.10	1.05	7.0	24.0	30.0	15.5	N/A	N/A	2.847
T6213 A	ALUM	0.75	No	0.755	0.759	2.15	2.15	0.50	-0.255	0.18	0.16	1.06	1.04	19.0	15.5	15.5	33.0	N/A	N/A	2.840
T6211 A	ALUM	0.75	No	0.755	0.759	2.16	2.16	0.50	-0.245	0.22	0.16	1.24	1.14	14.0	22.0	32.0	23.0	N/A	N/A	2.853
T6211 B	ALUM	0.75	No	0.755	0.759	2.16	2.15	0.50	-0.270	0.17	0.15	1.06	1.07	13.5	16.0	29.5	14.5	N/A	N/A	2.847
T6209 B	ALUM	0.75	No	0.755	0.759	2.18	2.17	0.25	-0.265	0.19	0.14	1.19	1.10	16.0	25.0	26.5	17.0	N/A	N/A	2.873
T6209 A	ALUM	0.75	No	0.755	0.759	2.15	2.19	0.25	-0.280	0.15	0.12	1.00	1.13	13.0	14.5	21.0	19.0	N/A	N/A	2.867
T6112 B	ALUM	0.75	No	0.750	0.754	2.15	2.18	0.25	0.000	0.22	0.22	1.21	1.26	31.0	21.0	30.0	31.0	N/A	N/A	2.879
T6112 A	ALUM	0.75	No	0.750	0.754	2.15	2.15	0.00	0.000	0.22	0.23	1.08	1.11	20.0	9.5	18.0	16.5	N/A	N/A	2.859
T6110 B	ALUM	0.75	No	0.750	0.754	2.15	2.18	0.00	-0.010	0.23	0.23	1.15	1.15	27.0	30.5	22.5	27.5	N/A	N/A	2.879
T6110 A	ALUM	0.75	No	0.750	0.754	2.14	2.15	0.00	-0.015	0.21	0.25	1.15	1.26	26.5	22.0	33.0	20.5	N/A	N/A	2.852
T6108 A	ALUM	0.75	No	0.750	0.754	2.15	2.15	0.00	-0.015	0.21	0.22	1.05	1.25	17.5	20.5	28.0	29.0	N/A	N/A	2.859
T6108 B	ALUM	0.75	No	0.750	0.754	2.13	2.15	0.00	0.005	0.21	0.21	1.13	1.18	29.0	15.0	19.0	17.5	N/A	N/A	2.846
T5915 B	ALUM	0.75	No	0.783	0.769	2.20	2.20	-10.25										N/A	N/A	2.835
T5915 A	ALUM	0.75	No	0.783	0.769	2.25	2.19	-10.75										N/A	N/A	2.861
T5913 B	ALUM	0.75	No	0.783	0.770	2.23	2.21	-10.75										N/A	N/A	2.859
T5913 A	ALUM	0.75	No	0.783	0.770	2.23	2.19	-10.25										N/A	N/A	2.846
T5911 B	ALUM	0.75	No	0.783	0.771	2.25	2.18	-10.00										N/A	N/A	2.851
T5911 A	ALUM	0.75	No	0.783	0.771	2.24	2.20	-10.25										N/A	N/A	2.857
T5816 B	ALUM	0.75	No	0.751	0.755	2.17	2.17	0.50	-0.31	0.24	0.24	1.32	1.37	21.0	33.0	27.0	18.0	N/A	N/A	2.882
T5816 A	ALUM	0.75	No	0.751	0.755	2.16	2.16	-0.25	-0.285	0.26	0.26	1.30	1.34	21.0	30.0	38.0	14.5	N/A	N/A	2.869
T5814 B	ALUM	0.75	No	0.752	0.755	2.14	2.16	0.50	-0.320	0.23	0.23	1.28	1.28	13.5	31.5	37.0	10.0	N/A	N/A	2.853
T5814 A	ALUM	0.75	No	0.752	0.755	2.15	2.16	0.25	-0.325	0.25	0.25	1.26	1.33	13.5	27.0	38.5	13.5	N/A	N/A	2.860
T5812 B	ALUM	0.75	No	0.752	0.755	2.17	2.17	0.75	-0.330	0.26	0.23	1.30	1.25	14.0	32.0	31.0	6.0	N/A	N/A	2.880
T5812 A	ALUM	0.75	No	0.752	0.755	2.12	2.13	0.25	-0.315	0.25	0.33	1.30	1.29	18.0	38.5	36.0	30.0	N/A	N/A	2.820
T5713 A	ALUM	0.75	No	0.758	0.759	2.55	2.56	-0.25	-0.015	0.28	0.27	1.60	1.55	43.0	21.0	18.5	23.0	N/A	N/A	3.368
T5713 B	ALUM	0.75	No	0.758	0.759	2.59	2.59	-0.25	-0.005	0.29	0.28	1.88	1.62	28.5	32.0	29.5	26.5	N/A	N/A	3.415
T5711 A	ALUM	0.75	No	0.757	0.758	2.58	2.61	0.50	0.005	0.25	0.30	1.63	1.50	35.5	32.0	37.0	23.0	N/A	N/A	3.426
T5711 B	ALUM	0.75	No	0.757	0.758	2.56	2.59	0.50	0.010	0.26	0.25	1.61	1.59	40.0	27.0	30.0	40.0	N/A	N/A	3.399
T5709 B	ALUM	0.75	No	0.757	0.759	2.61	2.57	0.25	-0.035	0.28	0.26	1.50	1.60	21.5	18.5	28.0	23.0	N/A	N/A	3.417
T5709 A	ALUM	0.75	No	0.757	0.759	2.59	2.60	0.00	-0.015	0.30	0.26	1.60	1.46	32.0	33.0	16.5	18.0	N/A	N/A	3.423

Table 4.4

PHOTO IDENT: 2 PIX PER SAMPLE	MTRL	THICK	SHAV	PLATE THICKNES		MEASUREMENTS FROM MACROPHOTOGRAPHS														PHOTO MAG.
						PLATE THICKN.				WELD REINFORC		WELD WIDT.		FUSION LINE ANGLES					CRN/ROOT	
SAMPLE	MTRL	THICK	SHAV	A	B	A	B	PEAKING	MISMATC	CROWN	ROOT	CROWN	ROOT	1/5	2/6	3/7	4/8	CROW DEPT	INTERSEC WIDTH	MAG.
P2314 A	ALUM	0.75	No	0.760	0.777	2.15	2.18	-1.00	0.035	0.35	0.55	1.84	1.35	41.5	12.0	10.0	3.5	0.50	1.63	2.817
P2314 B	ALUM	0.75	No	0.760	0.777	2.15	2.19	-1.25	0.035	0.31	0.56	1.79	1.29	36.0	15.5	7.5	0.0	0.55	1.62	2.824
P2312 B	ALUM	0.75	No	0.759	0.778	2.14	2.21	-1.75	0.030	0.30	0.56	1.85	1.35	36.0	6.5	-1.0	3.5	0.57	1.68	2.830
P2312 A	ALUM	0.75	No	0.759	0.778	2.17	2.22	-1.00	0.030	0.30	0.51	1.91	1.40	13.5	26.0	0.0	2.0	0.53	1.82	2.856
P2310 B	ALUM	0.75	No	0.759	0.778	2.15	2.20	-1.25	0.040	0.30	0.53	1.74	1.27	32.0	-0.5	18.5	10.0	0.55	1.60	2.830
P2310 A	ALUM	0.75	No	0.759	0.778	2.17	2.22	-1.50	0.035	0.37	0.54	1.78	1.29	9.0	4.0	-3.0	-2.5	0.50	1.76	2.856
P2212 A	ALUM	0.75	No	0.756	0.756	2.57	2.56	-1.75	-0.465	0.30	0.60	2.14	1.77	8.5	21.5	8.0	2.5	0.68	1.97	3.393
P2212 B	ALUM	0.75	No	0.756	0.756	2.56	2.56	-2.00	-0.345	0.28	0.62	2.10	1.76	18.5	13.5	14.5	-11.5	0.65	1.96	3.386
P2210 A	ALUM	0.75	No	0.756	0.755	2.56	2.52	-2.00	-0.380	0.27	0.55	2.08	1.70	25.0	22.0	7.0	-3.0	0.65	1.93	3.362
P2210 B	ALUM	0.75	No	0.756	0.755	2.53	2.59	-1.50	-0.390	0.29	0.55	2.16	1.70	38.5	39.0	10.0	1.0	0.61	1.84	3.388
P2208 B	ALUM	0.75	No	0.757	0.756	2.59	2.55	-2.25	-0.385	0.28	0.63	2.10	1.75	19.0	27.0	11.5	8.0	0.69	1.86	3.397
P2208 A	ALUM	0.75	No	0.757	0.756	2.58	2.57	-1.25	-0.445	0.29	0.61	2.10	1.77	12.5	27.5	4.0	2.5	0.60	1.94	3.404
P2110 B	ALUM	0.75	No	0.760	0.751	2.55	2.54	-2.75	0.025	0.38	0.60	2.29	2.54	28.5	26.5	14.0	10.0	0.60	1.95	3.369
P2110 A	ALUM	0.75	No	0.760	0.751	2.57	2.45	-2.50	0.000	0.42	0.49	2.47	1.45	30.5	32.5	2.5	7.0	0.57	2.03	3.322
P2108 A	ALUM	0.75	No	0.761	0.750	2.54	2.55	-1.25	-0.065	0.37	0.59	2.30	2.48	4.0	25.0	-1.5	-1.0	0.63	2.01	3.369
P2108 B	ALUM	0.75	No	0.761	0.750	2.53	2.52	-1.50	0.005	0.41	0.59	2.35	1.62	40.0	34.0	2.0	9.0	0.60	1.96	3.342
P2106 A	ALUM	0.75	No	0.760	0.751	2.60	2.56	-2.50	-0.075	0.39	0.52	2.28	1.46	20.0	24.5	4.5	13.5	0.59	2.03	3.415
P2106 B	ALUM	0.75	No	0.760	0.751	2.55	2.54	-2.00	-0.010	0.41	0.57	2.31	1.67	21.5	31.0	13.0	9.0	0.61	2.07	3.369
P1912 B	ALUM	0.75	No	0.751	0.751	2.15	2.13	-0.75	0.020	0.39	0.48	2.40	1.24	36.5	11.0	1.5	0.0	1.11	1.59	2.850
P1912 A	ALUM	0.75	No	0.751	0.751	2.16	2.16	-1.25	0.010	0.39	0.53	2.35	1.30	25.0	22.0	4.0	3.5	1.12	1.62	2.876
P1910 B	ALUM	0.75	No	0.750	0.751	2.12	2.13	-1.25	-0.005	0.41	0.46	2.19	1.21	18.5	14.5	2.5	-4.0	1.19	1.55	2.831
P1910 A	ALUM	0.75	No	0.750	0.751	2.10	2.13	-1.00	0.000	0.39	0.53	2.25	1.30	20.0	15.5	8.5	5.5	0.95	1.56	2.818
P1908 A	ALUM	0.75	No	0.749	0.752	2.18	2.18	-0.50	0.040	0.41	0.53	2.31	1.23	28.0	10.5	-3.5	1.0	1.05	1.57	2.905
P1908 B	ALUM	0.75	No	0.749	0.752	2.12	2.14	-1.25	0.025	0.39	0.53	2.32	1.38	18.0	12.0	3.0	-2.5	1.11	1.62	2.838
P1820 A	ALUM	0.75	No	0.772	0.775	2.63	2.62	-1.00	-0.360	0.39	0.70	2.67	1.73	18.5	22.0	7.5	-2.0	1.19	1.92	3.394
P1820 B	ALUM	0.75	No	0.772	0.775	2.62	2.63	-0.75	-0.350	0.39	0.68	2.57	1.79	18.0	14.0	7.0	1.5	1.21	1.87	3.394
P1819 A	ALUM	0.75	No	0.772	0.773	2.63	2.63	-2.50	-0.380	0.37	0.75	2.50	1.70	19.5	24.0	12.0	-5.0	1.18	2.03	3.405
P1819 B	ALUM	0.75	No	0.772	0.773	2.59	2.59	-0.75	-0.340	0.40	0.65	2.65	1.70	15.0	23.5	22.0	-2.0	1.10	1.91	3.353
P1818 B	ALUM	0.75	No	0.772	0.774	2.63	2.60	-0.50	-0.370	0.39	0.69	2.47	1.80	11.0	15.0	16.0	20.0	1.18	1.92	3.383
P1818 A	ALUM	0.75	No	0.772	0.774	2.63	2.62	0.25	-0.375	0.33	0.75	2.43	1.72	12.5	28.5	4.0	0.0	1.32	1.98	3.396
P1718 B	ALUM	0.75	No	0.756	0.754	2.15	2.17	-0.25	0.000	0.37	0.56	2.27	1.25	36.0	29.0	6.5	-3.0	1.22	1.59	2.861
P1718 A	ALUM	0.75	No	0.756	0.754	2.18	2.17	-0.25	0.010	0.38	0.56	2.16	1.23	26.0	23.0	-1.0	7.0	1.17	1.66	2.881
P1717 B	ALUM	0.75	No	0.757	0.755	2.13	2.13	-2.00	0.000	0.37	0.55	2.17	1.24	35.5	29.5	2.0	5.5	1.19	1.61	2.817
P1717 A	ALUM	0.75	No	0.757	0.755	2.14	2.13	-1.50	0.010	0.28	0.55	2.23	1.24	30.0	31.5	8.0	4.0	1.19	1.54	2.824
P1706 A	ALUM	0.75	No	0.756	0.756	2.18	2.15	-1.75	0.000	0.35	0.51	2.14	1.23	21.0	18.5	11.0	8.5	0.85	1.56	2.864
P1706 B	ALUM	0.75	No	0.756	0.756	2.13	2.14	-2.00	-0.025	0.33	0.50	2.21	1.17	17.0	24.5	7.0	8.0	0.90	1.60	2.824

Table 4.4

PHOTO IDENT: 2 PIX PER SAMPLE	MTRI	THICK	SHAV	PLATE THICKNES		MEASUREMENTS FROM MACROPHOTOGRAPHS														PHOTO MAG.
						PLATE THICKN				WELD REINFORC		WELD WIDT		FUSION LINE ANGLES					CRN/ROOT	
				A	B	A	B	PEAKING	MISMATC	CROWN	ROOT	CROWN	ROOT	1/5	2/6	3/7	4/8	CROV DEPT	INTERSEC WIDTH	
T6318 A	ALUM	0.75	Yes	0.753	0.756	2.15	2.10	-9.75										N/A	N/A	2.816
T6318 B	ALUM	0.75	Yes	0.753	0.756	2.16	2.16	-9.25										N/A	N/A	2.863
T6316 A	ALUM	0.75	Yes	0.753	0.755	2.14	2.19	-9.25										N/A	N/A	2.871
T6316 B	ALUM	0.75	Yes	0.753	0.755	2.12	2.13	-9.75										N/A	N/A	2.818
T6314 B	ALUM	0.75	Yes	0.755	0.755	2.12	2.16	-10.25										N/A	N/A	2.834
T6314 A	ALUM	0.75	Yes	0.755	0.755	2.20	2.20	-9.75										N/A	N/A	2.914
T6214 B	ALUM	0.75	Yes	0.755	0.761	2.16	2.17	0.50										N/A	N/A	2.856
T6214 A	ALUM	0.75	Yes	0.755	0.761	2.17	2.16	0.25										N/A	N/A	2.856
T6212 A	ALUM	0.75	Yes	0.755	0.759	2.18	2.19	0.75										N/A	N/A	2.886
T6212 B	ALUM	0.75	Yes	0.755	0.759	2.15	2.17	0.00										N/A	N/A	2.853
T6210 B	ALUM	0.75	Yes	0.756	0.758	2.15	2.17	0.50										N/A	N/A	2.853
T6210 A	ALUM	0.75	Yes	0.756	0.758	2.14	2.07	-0.50										N/A	N/A	2.781
T6113 B	ALUM	0.75	Yes	0.750	0.753	2.10	2.15	0.50	-0.010	0.00	0.00	0.95	1.11	13.0	9.0	22.0	18.0	N/A	N/A	2.828
T6113 A	ALUM	0.75	Yes	0.750	0.753	2.10	2.13	0.25	0.000	0.02	0.00	1.04	1.04	22.5	15.0	9.0	9.0	N/A	N/A	2.814
T6111 A	ALUM	0.75	Yes	0.750	0.753	2.14	2.13	0.00	0.000	0.00	0.00	1.04	1.07	21.0	16.0	16.5	18.0	N/A	N/A	2.841
T6111 B	ALUM	0.75	Yes	0.750	0.753	2.14	2.17	0.00	0.015	0.00	0.00	0.96	1.04	15.0	6.5	7.0	12.0	N/A	N/A	2.868
T6109 B	ALUM	0.75	Yes	0.751	0.753	2.14	2.14	0.25	0.000	0.00	0.00	0.89	1.02	6.0	7.0	17.0	10.0	N/A	N/A	2.846
T6109 A	ALUM	0.75	Yes	0.751	0.753	2.13	2.13	-0.50	0.000	0.00	0.00	0.91	1.05	8.0	7.0	19.0	17.0	N/A	N/A	2.832
T5914 A	ALUM	0.75	Yes	0.783	0.770	2.24	2.18	-10.50										N/A	N/A	2.846
T5914 B	ALUM	0.75	Yes	0.783	0.770	2.20	2.18	-11.25										N/A	N/A	2.820
T5912 B	ALUM	0.75	Yes	0.783	0.770	2.22	2.22	-10.50										N/A	N/A	2.859
T5912 A	ALUM	0.75	Yes	0.783	0.770	2.25	2.21	-12.00										N/A	N/A	2.872
T5910 B	ALUM	0.75	Yes	0.783	0.770	2.23	2.17	-10.25										N/A	N/A	2.833
T5910 A	ALUM	0.75	Yes	0.783	0.770	2.24	2.18	-11.75										N/A	N/A	2.846
T5817 A	ALUM	0.75	Yes	0.750	0.755	2.17	2.16	0.50										N/A	N/A	2.877
T5817 B	ALUM	0.75	Yes	0.750	0.755	2.14	2.16	0.25										N/A	N/A	2.857
T5815 A	ALUM	0.75	Yes	0.750	0.754	2.12	2.13	0.75										N/A	N/A	2.826
T5815 B	ALUM	0.75	Yes	0.750	0.754	2.14	2.12	0.00										N/A	N/A	2.832
T5813 B	ALUM	0.75	Yes	0.752	0.755	2.14	2.18	0.00										N/A	N/A	2.867
T5813 A	ALUM	0.75	Yes	0.752	0.755	2.16	2.17	1.00										N/A	N/A	2.873
T5712 B	ALUM	0.75	Yes	0.757	0.757	2.15	2.15	0.25	0.015	0.00	0.00	1.26	1.22	23.0	26.0	24.0	14.0	N/A	N/A	2.840
T5712 A	ALUM	0.75	Yes	0.757	0.757	2.14	2.13	0.00	0.000	0.00	0.00	1.22	1.24	29.5	31.0	34.0	20.0	N/A	N/A	2.820
T5710 B	ALUM	0.75	Yes	0.756	0.757	2.17	2.17	0.50	0.040	0.00	0.00	1.22	1.23	26.5	22.5	27.5	26.5	N/A	N/A	2.868
T5710 A	ALUM	0.75	Yes	0.756	0.757	2.15	2.14	0.00	0.000	0.00	0.00	1.20	1.28	24.5	14.0	23.0	12.5	N/A	N/A	2.835
T5708 B	ALUM	0.75	Yes	0.756	0.758	2.15	2.15	1.00	0.025	0.00	0.00	1.23	1.10	34.5	19.5	7.0	11.0	N/A	N/A	2.840
T5708 A	ALUM	0.75	Yes	0.756	0.758	2.17	2.17	-0.75	-0.015	0.00	0.00	1.18	1.20	19.0	17.0	18.0	8.0	N/A	N/A	2.867
P2315 B	ALUM	0.75	Yes	0.757	0.778	2.14	2.21	-1.25												2.834

Table 4.4

PHOTO IDENT: 2 PIX PER SAMPLE	MTRL	THICK	SHAV	PLATE THICKNES		MEASUREMENTS FROM MACROPHOTOGRAPHS														
						PLATE THICKN				WELD REINFORC		WELD WIDT		FUSION LINE ANGLES					CRN/ROOT	
SAMPLE	MTRI	THICK	SHAV	A	B	A	B	PEAKINC	MISMATC	CROWN	ROOT	CROWN	ROOT	1/5	2/6	3/7	4/8	CROW DEPT	INTERSEC WIDTH	PHOTO MAG.
P2315 A	ALUM	0.75	Yes	0.757	0.778	2.12	2.18	-1.25												2.801
P2313 A	ALUM	0.75	Yes	0.758	0.777	2.16	2.22	-2.25												2.853
P2313 B	ALUM	0.75	Yes	0.758	0.777	2.18	2.23	-1.25												2.873
P2311 A	ALUM	0.75	Yes	0.758	0.757	2.16	2.23	-0.75												2.898
P2311 B	ALUM	0.75	Yes	0.758	0.757	2.18	2.13	0.00												2.845
P2211 B	ALUM	0.75	Yes	0.753	0.755	2.13	2.13	-0.25												2.825
P2211 A	ALUM	0.75	Yes	0.753	0.755	2.13	2.10	-0.25												2.805
P2209 B	ALUM	0.75	Yes	0.753	0.754	2.19	2.19	-0.50												2.906
P2209 A	ALUM	0.75	Yes	0.753	0.754	2.15	2.09	-0.25												2.814
P2207 B	ALUM	0.75	Yes	0.754	0.754	2.15	2.17	-1.50												2.865
P2207 A	ALUM	0.75	Yes	0.754	0.754	2.11	2.09	0.75												2.785
P2109 A	ALUM	0.75	Yes	0.759	0.748	2.13	2.13	0.00												2.827
P2109 B	ALUM	0.75	Yes	0.759	0.748	2.17	2.15	-1.50												2.867
P2107 B	ALUM	0.75	Yes	0.759	0.748	2.18	2.16	-0.50												2.880
P2107 A	ALUM	0.75	Yes	0.759	0.748	2.16	2.13	-0.50												2.847
P2105 B	ALUM	0.75	Yes	0.760	0.747	2.16	2.15	-0.50												2.860
P2105 A	ALUM	0.75	Yes	0.760	0.747	2.16	2.13	-1.75												2.847
P1913 A	ALUM	0.75	Yes	0.750	0.750	2.13	2.13	-1.00												2.840
P1913 B	ALUM	0.75	Yes	0.750	0.750	2.16	2.16	-0.75												2.880
P1911 A	ALUM	0.75	Yes	0.750	0.752	2.12	2.13	-1.25												2.830
P1911 B	ALUM	0.75	Yes	0.750	0.752	2.13	2.15	-1.00												2.850
P1909 A	ALUM	0.75	Yes	0.749	0.751	2.16	2.14	-1.75												2.867
P1909 B	ALUM	0.75	Yes	0.749	0.751	2.11	2.13	-1.00												2.827
P1816 A	ALUM	0.75	Yes	0.772	0.773	2.24	2.24	-1.50												2.900
P1816 B	ALUM	0.75	Yes	0.772	0.773	2.20	2.21	-1.50												2.854
P1815 B	ALUM	0.75	Yes	0.771	0.772	2.18	2.18	-0.50												2.826
P1815 A	ALUM	0.75	Yes	0.771	0.772	2.20	2.19	-1.25												2.845
P1810 B	ALUM	0.75	Yes	0.772	0.772	2.20	2.19	0.50												2.843
P1810 A	ALUM	0.75	Yes	0.772	0.772	2.23	2.18	-3.00												2.856
P1720 B	ALUM	0.75	Yes	0.756	0.754	2.15	2.15	-0.50	0.000	0.00	0.00	2.26	1.29	29.0	24.0	-2.5	-7.0	1.28	1.63	2.848
P1720 A	ALUM	0.75	Yes	0.756	0.754	2.16	2.12	-1.75	-0.020	0.00	0.00	2.25	1.28	39.5	35.0	-6.5	-5.0	1.21	1.66	2.834
P1719 A	ALUM	0.75	Yes	0.757	0.754	2.18	2.14	-1.00	0.000	0.00	0.00	2.22	1.30	28.5	34.5	7.0	-8.0	1.19	1.63	2.859
P1719 B	ALUM	0.75	Yes	0.757	0.754	2.15	2.14	0.00	0.000	0.00	0.00	2.29	1.25	35.0	34.0	-9.0	-5.5	1.30	1.66	2.839
P1707 A	ALUM	0.75	Yes	0.756	0.755	2.15	2.12	-1.00	-0.025	0.00	0.00	2.17	1.08	20.0	22.5	-13.5	-8.0	0.88	1.65	2.826
P1707 B	ALUM	0.75	Yes	0.756	0.755	2.18	2.17	-0.50	0.000	0.00	0.00	2.31	1.11	27.0	17.5	-12.0	-12.0	0.87	1.63	2.879

Table 4.4

GEOMET

FILE C:\GDIMENSIONS (MEASUREMENTS CORRECTED FOR PHOTO MAG.)

PHOTO IDENT: 2 PIX PER SAMPLE	MISMATC	WELD REINFORC. CROWN	WELD REINFORC. ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	TENSILE TEST RESUL UTS (ksi)	TENSILE TEST RESUL 0.20% Y.S. (ksi)	TENSILE TEST RESUL % Elong
T6319 A	0.000	0.000	0.000	0.000	0.000	32.6	0.0	3.4
T6319 B	0.000	0.000	0.000	0.000	0.000	32.6	0.0	3.4
T6317 A	0.000	0.000	0.000	0.000	0.000	31.3	21.2	4.2
T6317 B	0.000	0.000	0.000	0.000	0.000	31.3	21.2	4.2
T6315 B	0.000	0.000	0.000	0.000	0.000	29.0	17.1	5.0
T6315 A	0.000	0.000	0.000	0.000	0.000	29.0	17.1	5.0
T6213 B	-0.090	0.056	0.046	0.386	0.369	41.0	22.0	4.6
T6213 A	-0.090	0.063	0.056	0.373	0.386	41.0	22.0	4.6
T6211 A	-0.086	0.077	0.056	0.435	0.400	41.0	20.1	5.3
T6211 B	-0.095	0.060	0.053	0.372	0.376	41.0	20.1	5.3
T6209 B	-0.092	0.066	0.049	0.414	0.383	40.7	22.5	5.3
T6209 A	-0.098	0.052	0.042	0.349	0.394	40.7	22.5	5.3
T6112 B	0.000	0.076	0.076	0.420	0.445	45.2	23.0	7.0
T6112 A	0.000	0.077	0.080	0.378	0.388	45.2	23.0	7.0
T6110 B	-0.003	0.080	0.080	0.399	0.399	44.9	22.0	2.3
T6110 A	-0.005	0.074	0.088	0.403	0.442	44.9	22.0	2.3
T6108 A	-0.005	0.073	0.077	0.367	0.437	44.3	22.7	6.5
T6108 B	0.002	0.074	0.074	0.397	0.415	44.3	22.7	6.5
T5915 B	0.000	0.000	0.000	0.000	0.000	27.7	18.3	3.3
T5915 A	0.000	0.000	0.000	0.000	0.000	27.7	18.3	3.3
T5913 B	0.000	0.000	0.000	0.000	0.000	25.5	0.0	3.1
T5913 A	0.000	0.000	0.000	0.000	0.000	25.5	0.0	3.1
T5911 B	0.000	0.000	0.000	0.000	0.000	25.3	2.8	2.6
T5911 A	0.000	0.000	0.000	0.000	0.000	25.3	2.8	2.6
T5816 B	-0.108	0.083	0.083	0.458	0.475	36.9	24.1	3.9
T5816 A	-0.099	0.091	0.091	0.453	0.467	36.9	24.1	3.9
T5814 B	-0.112	0.081	0.081	0.449	0.449	36.6	23.5	4.2
T5814 A	-0.114	0.087	0.087	0.441	0.465	36.6	23.5	4.2
T5812 B	-0.115	0.090	0.080	0.451	0.434	37.2	21.2	4.2
T5812 A	-0.112	0.089	0.117	0.461	0.457	37.2	21.2	4.2
T5713 A	-0.004	0.083	0.080	0.475	0.460	44.5	24.2	6.9
T5713 B	-0.001	0.085	0.082	0.551	0.474	44.5	24.2	6.9
T5711 A	0.001	0.073	0.088	0.476	0.438	44.4	25.1	7.0
T5711 B	0.003	0.076	0.074	0.474	0.468	44.4	25.1	7.0
T5709 B	-0.010	0.082	0.076	0.439	0.468	44.5	21.6	7.1
T5709 A	-0.004	0.088	0.076	0.467	0.426	44.5	21.6	7.1

Table 4.4

PHOTO IDENT: 2 PIX PER SAMPLE	MISMATC	WELD REINFORC. CROWN	WELD REINFORC. ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	TENSILE TEST RESUL UTS (ksi)	TENSILE TEST RESUL 0.20% Y.S. (ksi)	TENSILE TEST RESUL % Elong
P2314 A	0.012	0.124	0.195	0.653	0.479	34.4	14.1	2.3
P2314 B	0.012	0.110	0.198	0.634	0.457	34.4	14.1	2.3
P2312 B	0.011	0.106	0.198	0.654	0.477	35.7	18.9	3.5
P2312 A	0.011	0.105	0.179	0.669	0.490	35.7	18.9	3.5
P2310 B	0.014	0.106	0.187	0.615	0.449	35.2	16.4	3.7
P2310 A	0.012	0.130	0.189	0.623	0.452	35.2	16.4	3.7
P2212 A	-0.137	0.088	0.177	0.631	0.522	27.7	15.9	4.0
P2212 B	-0.102	0.083	0.183	0.620	0.520	27.7	15.9	4.0
P2210 A	-0.113	0.080	0.164	0.619	0.506	27.9	16.2	2.8
P2210 B	-0.115	0.086	0.162	0.637	0.502	27.9	16.2	2.8
P2208 B	-0.113	0.082	0.185	0.618	0.515	27.4	14.3	3.3
P2208 A	-0.131	0.085	0.179	0.617	0.520	27.4	14.3	3.3
P2110 B	0.007	0.113	0.178	0.680	0.754	35.6	14.6	4.0
P2110 A	0.000	0.126	0.147	0.743	0.436	35.6	14.6	4.0
P2108 A	-0.019	0.110	0.175	0.683	0.736	37.6	20.3	3.5
P2108 B	0.001	0.123	0.177	0.703	0.485	37.6	20.3	3.5
P2106 A	-0.022	0.114	0.152	0.668	0.428	36.7	18.4	3.7
P2106 B	-0.003	0.122	0.169	0.686	0.496	36.7	18.4	3.7
P1912 B	0.007	0.137	0.168	0.842	0.435	37.0	16.1	5.4
P1912 A	0.003	0.136	0.184	0.817	0.452	37.0	16.1	5.4
P1910 B	-0.002	0.145	0.162	0.773	0.427	37.3	16.7	5.5
P1910 A	0.000	0.138	0.188	0.798	0.461	37.3	16.7	5.5
P1908 A	0.014	0.141	0.182	0.795	0.423	35.7	17.1	3.8
P1908 B	0.009	0.137	0.187	0.817	0.486	35.7	17.1	3.8
P1820 A	-0.106	0.115	0.206	0.787	0.510	28.2	17.5	2.3
P1820 B	-0.103	0.115	0.200	0.757	0.527	28.2	17.5	2.3
P1819 A	-0.112	0.109	0.220	0.734	0.499	28.6	19.0	2.2
P1819 B	-0.101	0.119	0.194	0.790	0.507	28.6	19.0	2.2
P1818 B	-0.109	0.115	0.204	0.730	0.532	28.5	15.3	2.6
P1818 A	-0.110	0.097	0.221	0.716	0.506	28.5	15.3	2.6
P1718 B	0.000	0.129	0.196	0.793	0.437	36.8	14.5	6.0
P1718 A	0.003	0.132	0.194	0.750	0.427	36.8	14.5	6.0
P1717 B	0.000	0.131	0.195	0.770	0.440	37.2	16.0	5.9
P1717 A	0.004	0.099	0.195	0.790	0.439	37.2	16.0	5.9
P1706 A	0.000	0.122	0.178	0.747	0.430	37.1	15.8	5.2
P1706 B	-0.009	0.117	0.177	0.783	0.414	37.1	15.8	5.2

Table 4.4

PHOTO IDENT: 2 PIX PER SAMPLE		MISMATC	WELD REINFORC CROWN	WELD REINFORC ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	TENSILE TEST RESUL UTS (ksi)	0.20% Y.S. (ksi)	% Elong
T6318	A	0.000	0.000	0.000	0.000	0.000	41.5	0.0	6.1
T6318	B	0.000	0.000	0.000	0.000	0.000	41.5	0.0	6.1
T6316	A	0.000	0.000	0.000	0.000	0.000	41.1	0.0	5.3
T6316	B	0.000	0.000	0.000	0.000	0.000	41.1	0.0	5.3
T6314	B	0.000	0.000	0.000	0.000	0.000	41.5	0.0	5.2
T6314	A	0.000	0.000	0.000	0.000	0.000	41.5	0.0	5.2
T6214	B	0.000	0.000	0.000	0.000	0.000	41.6	19.8	5.5
T6214	A	0.000	0.000	0.000	0.000	0.000	41.6	19.8	5.5
T6212	A	0.000	0.000	0.000	0.000	0.000	42.5	22.3	6.0
T6212	B	0.000	0.000	0.000	0.000	0.000	42.5	22.3	6.0
T6210	B	0.000	0.000	0.000	0.000	0.000	40.4	21.3	6.0
T6210	A	0.000	0.000	0.000	0.000	0.000	40.4	21.3	6.0
T6113	B	-0.004	0.000	0.000	0.336	0.393	43.4	19.9	6.0
T6113	A	0.000	0.007	0.000	0.370	0.370	43.4	19.9	6.0
T6111	A	0.000	0.000	0.000	0.366	0.377	45.1	21.8	6.8
T6111	B	0.005	0.000	0.000	0.335	0.363	45.1	21.8	6.8
T6109	B	0.000	0.000	0.000	0.313	0.358	43.4	19.4	7.4
T6109	A	0.000	0.000	0.000	0.321	0.371	43.4	19.4	7.4
T5914	A	0.000	0.000	0.000	0.000	0.000	37.7	0.0	4.6
T5914	B	0.000	0.000	0.000	0.000	0.000	37.7	0.0	4.6
T5912	B	0.000	0.000	0.000	0.000	0.000	36.4	27.1	5.2
T5912	A	0.000	0.000	0.000	0.000	0.000	36.4	27.1	5.2
T5910	B	0.000	0.000	0.000	0.000	0.000	34.2	26.8	4.8
T5910	A	0.000	0.000	0.000	0.000	0.000	34.2	26.8	4.8
T5817	A	0.000	0.000	0.000	0.000	0.000	41.2	22.4	5.7
T5817	B	0.000	0.000	0.000	0.000	0.000	41.2	22.4	5.7
T5815	A	0.000	0.000	0.000	0.000	0.000	37.8	18.3	5.7
T5815	B	0.000	0.000	0.000	0.000	0.000	37.8	18.3	5.7
T5813	B	0.000	0.000	0.000	0.000	0.000	40.1	19.9	6.0
T5813	A	0.000	0.000	0.000	0.000	0.000	40.1	19.9	6.0
T5712	B	0.005	0.000	0.000	0.444	0.430	41.9	20.1	7.3
T5712	A	0.000	0.000	0.000	0.433	0.440	41.9	20.1	7.3
T5710	B	0.014	0.000	0.000	0.425	0.429	42.6	19.9	7.3
T5710	A	0.000	0.000	0.000	0.423	0.451	42.6	19.9	7.3
T5708	B	0.009	0.000	0.000	0.433	0.387	42.0	20.8	6.8
T5708	A	-0.005	0.000	0.000	0.412	0.419	42.0	20.8	6.8
P2315	B	0.000	0.000	0.000	0.000	0.000	41.0	19.1	7.8

Table 4.4

PHOTO IDENT: 2 PIX PER SAMPLE		WELD REINFORC		WELD WIDTH		TENSILE TEST RESUL		
	MISMATC	CROWN	ROOT	CROWN	ROOT	UTS (ksi)	0.20% Y.S. (ksi)	% Elong
P2315 A	0.000	0.000	0.000	0.000	0.000	41.0	19.1	7.8
P2313 A	0.000	0.000	0.000	0.000	0.000	40.1	18.9	9.4
P2313 B	0.000	0.000	0.000	0.000	0.000	40.1	18.9	9.4
P2311 A	0.000	0.000	0.000	0.000	0.000	40.7	19.7	8.0
P2311 B	0.000	0.000	0.000	0.000	0.000	40.7	19.7	8.0
P2211 B	0.000	0.000	0.000	0.000	0.000	38.0	17.7	7.5
P2211 A	0.000	0.000	0.000	0.000	0.000	38.0	17.7	7.5
P2209 B	0.000	0.000	0.000	0.000	0.000	38.0	15.8	7.9
P2209 A	0.000	0.000	0.000	0.000	0.000	38.0	15.8	7.9
P2207 B	0.000	0.000	0.000	0.000	0.000	36.8	14.0	6.9
P2207 A	0.000	0.000	0.000	0.000	0.000	36.8	14.0	6.9
P2109 A	0.000	0.000	0.000	0.000	0.000	38.7	17.6	9.0
P2109 B	0.000	0.000	0.000	0.000	0.000	38.7	17.6	9.0
P2107 B	0.000	0.000	0.000	0.000	0.000	39.9	18.8	9.0
P2107 A	0.000	0.000	0.000	0.000	0.000	39.9	18.8	9.0
P2105 B	0.000	0.000	0.000	0.000	0.000	39.9	19.5	8.7
P2105 A	0.000	0.000	0.000	0.000	0.000	39.9	19.5	8.7
P1913 A	0.000	0.000	0.000	0.000	0.000	39.6	15.4	11.0
P1913 B	0.000	0.000	0.000	0.000	0.000	39.6	15.4	11.0
P1911 A	0.000	0.000	0.000	0.000	0.000	39.6	15.9	10.8
P1911 B	0.000	0.000	0.000	0.000	0.000	39.6	15.9	10.8
P1909 A	0.000	0.000	0.000	0.000	0.000	39.2	13.9	10.3
P1909 B	0.000	0.000	0.000	0.000	0.000	39.2	13.9	10.3
P1816 A	0.000	0.000	0.000	0.000	0.000	34.5	14.5	6.0
P1816 B	0.000	0.000	0.000	0.000	0.000	34.5	14.5	6.0
P1815 B	0.000	0.000	0.000	0.000	0.000	37.1	16.3	5.7
P1815 A	0.000	0.000	0.000	0.000	0.000	37.1	16.3	5.7
P1810 B	0.000	0.000	0.000	0.000	0.000	36.5	0.0	5.9
P1810 A	0.000	0.000	0.000	0.000	0.000	36.5	0.0	5.9
P1720 B	0.000	0.000	0.000	0.794	0.453	39.8	15.3	10.7
P1720 A	-0.007	0.000	0.000	0.794	0.452	39.8	15.3	10.7
P1719 A	0.000	0.000	0.000	0.776	0.455	38.4	17.5	9.8
P1719 B	0.000	0.000	0.000	0.807	0.440	38.4	17.5	9.8
P1707 A	-0.009	0.000	0.000	0.768	0.382	38.8	17.6	7.0
P1707 B	0.000	0.000	0.000	0.802	0.386	38.8	17.6	7.0

Table 4.4

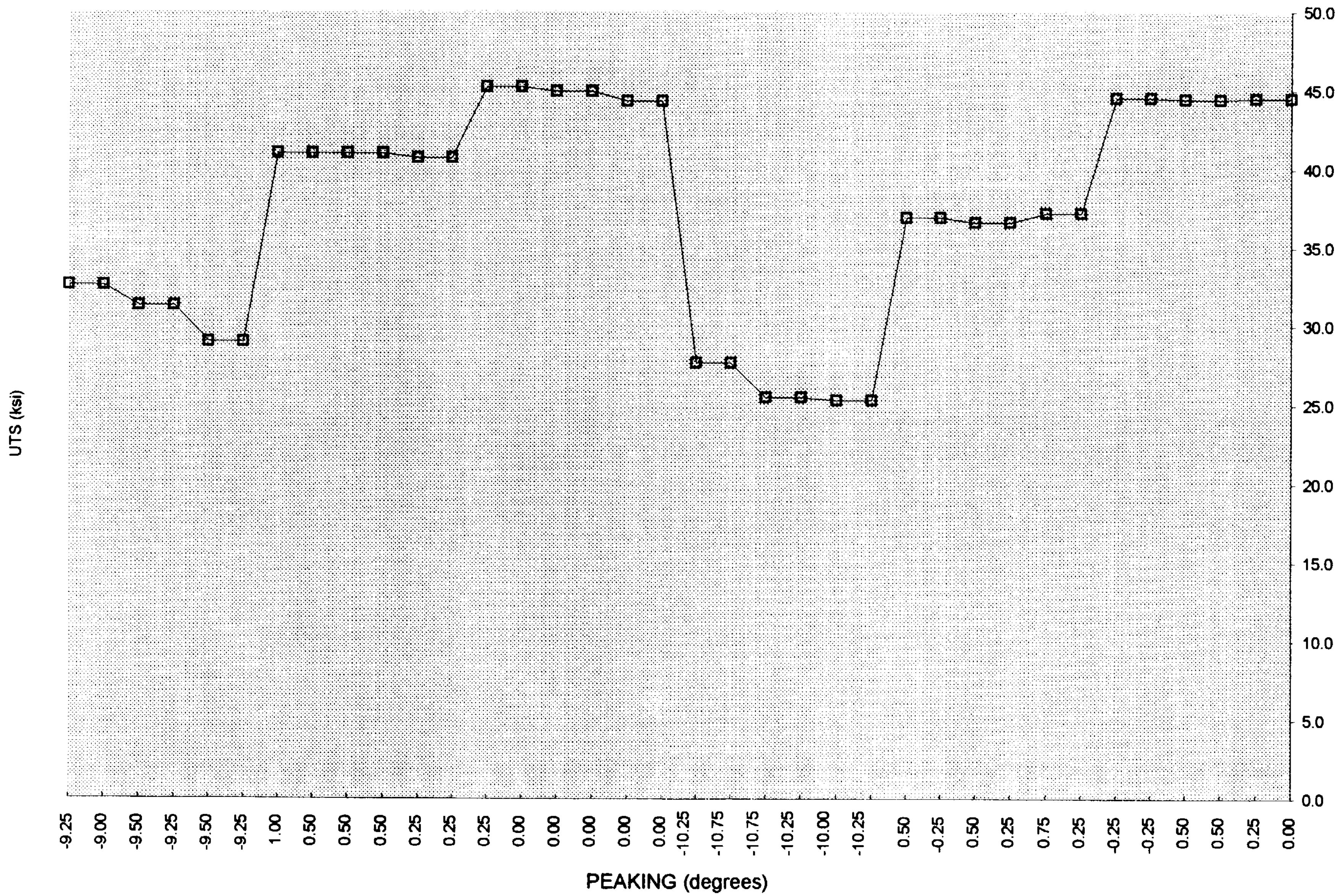

Table 4.4 Graph

GEOMETRY EFFECTS - GEOMETRY MEASUREMENTS AND TENSILE TEST RESULTS (5-23-94)
FILE C:\GEOM-FX\3AL4\mismatch.WK1

PHOTO IDENT: 2 PIX PER SAMPLE	MTR	THICK	SHAV	PLATE THICKNES A	PLATE THICKNES B	MEASUREMENTS FROM MACROPHOTOGRAPHS: PLATE THICKNES A	PLATE THICKNES B	PEAKIN	MISMATC	WELD REINFORC CROWN	WELD REINFORC ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	FUSION LINE ANGLE 1/5	FUSION LINE ANGLE 2/6	FUSION LINE ANGLE 3/7
P2207 A	ALUM	0.75	Yes	0.754	0.754	2.11	2.09	0.75	-0.410	0.00	0.00	1.60	1.33	-3.5	8.0	-5.5
P1816 B	ALUM	0.75	Yes	0.772	0.773	2.20	2.21	-1.50	-0.405	-0.02	-0.01	2.50	1.56	20.5	50.0	16.0
P2207 B	ALUM	0.75	Yes	0.754	0.754	2.15	2.17	-1.50	-0.395	0.00	0.00	1.68	1.46	-6.0	12.0	6.0
P2212 A	ALUM	0.75	No	0.756	0.756	2.57	2.56	-1.75	-0.465	0.30	0.60	2.14	1.77	8.5	21.5	8.0
P2211 A	ALUM	0.75	Yes	0.753	0.755	2.13	2.10	-0.25	-0.380	0.00	0.00	1.67	1.46	1.0	9.0	5.0
P2208 A	ALUM	0.75	No	0.757	0.756	2.58	2.57	-1.25	-0.445	0.29	0.61	2.10	1.77	12.5	27.5	4.0
P1816 A	ALUM	0.75	Yes	0.772	0.773	2.24	2.24	-1.50	-0.375	-0.04	0.00	2.40	1.45	17.0	44.5	13.0
P1810 B	ALUM	0.75	Yes	0.772	0.772	2.20	2.19	0.50	-0.365	0.07	0.00	2.23	1.30	20.0	39.5	7.0
P2209 B	ALUM	0.75	Yes	0.753	0.754	2.19	2.19	-0.50	-0.370	0.00	0.00	1.70	1.46	-4.0	13.0	8.0
P2209 A	ALUM	0.75	Yes	0.753	0.754	2.15	2.09	-0.25	-0.335	0.00	0.00	1.67	1.34	-4.0	8.0	-2.0
P1810 A	ALUM	0.75	Yes	0.772	0.772	2.23	2.18	-3.00	-0.335	0.00	0.00	2.44	1.25	22.5	35.5	2.0
P1815 A	ALUM	0.75	Yes	0.771	0.772	2.20	2.19	-1.25	-0.330	-0.02	0.03	2.42	1.30	25.0	41.0	15.0
P2210 B	ALUM	0.75	No	0.756	0.755	2.53	2.59	-1.50	-0.390	0.29	0.55	2.16	1.70	38.5	39.0	10.0
P1815 B	ALUM	0.75	Yes	0.771	0.772	2.18	2.18	-0.50	-0.325	0.00	0.00	2.54	1.35	16.0	49.0	9.5
P2208 B	ALUM	0.75	No	0.757	0.756	2.59	2.55	-2.25	-0.385	0.28	0.63	2.10	1.75	19.0	27.0	11.5
P2211 B	ALUM	0.75	Yes	0.753	0.755	2.13	2.13	-0.25	-0.320	0.00	0.00	1.82	1.47	1.0	9.0	3.5
P2210 A	ALUM	0.75	No	0.756	0.755	2.56	2.52	-2.00	-0.380	0.27	0.55	2.08	1.70	25.0	22.0	7.0
P1819 A	ALUM	0.75	No	0.772	0.773	2.63	2.63	-2.50	-0.380	0.37	0.75	2.50	1.70	19.5	24.0	12.0
P1818 A	ALUM	0.75	No	0.772	0.774	2.63	2.62	0.25	-0.375	0.33	0.75	2.43	1.72	12.5	28.5	4.0
P1818 B	ALUM	0.75	No	0.772	0.774	2.63	2.60	-0.50	-0.370	0.39	0.69	2.47	1.80	11.0	15.0	16.0
P1820 A	ALUM	0.75	No	0.772	0.775	2.63	2.62	-1.00	-0.360	0.39	0.70	2.67	1.73	18.5	22.0	7.5
P1820 B	ALUM	0.75	No	0.772	0.775	2.62	2.63	-0.75	-0.350	0.39	0.68	2.57	1.79	18.0	14.0	7.0
P2212 B	ALUM	0.75	No	0.756	0.756	2.56	2.56	-2.00	-0.345	0.28	0.62	2.10	1.76	18.5	13.5	14.5
P1819 B	ALUM	0.75	No	0.772	0.773	2.59	2.59	-0.75	-0.340	0.40	0.65	2.65	1.70	15.0	23.5	22.0
P2106 A	ALUM	0.75	No	0.760	0.751	2.60	2.56	-2.50	-0.075	0.39	0.52	2.28	1.46	20.0	24.5	4.5
P2108 A	ALUM	0.75	No	0.761	0.750	2.54	2.55	-1.25	-0.065	0.37	0.59	2.30	2.48	4.0	25.0	-1.5
P1913 A	ALUM	0.75	Yes	0.750	0.750	2.13	2.13	-1.00	-0.035	0.00	0.00	2.38	1.20	34.5	16.0	-4.0
P1706 B	ALUM	0.75	No	0.756	0.756	2.13	2.14	-2.00	-0.025	0.33	0.50	2.21	1.17	17.0	24.5	7.0
P1707 A	ALUM	0.75	Yes	0.756	0.755	2.15	2.12	-1.00	-0.025	0.00	0.00	2.17	1.08	20.0	22.5	-13.5
P1908 B	ALUM	0.75	No	0.749	0.752	2.12	2.14	-1.25	-0.025	0.39	0.53	2.32	1.38	18.0	12.0	3.0
P1911 B	ALUM	0.75	Yes	0.750	0.752	2.13	2.15	-1.00	-0.025	0.00	0.00	2.26	1.25	9.0	14.0	-2.5
P1909 B	ALUM	0.75	Yes	0.749	0.751	2.11	2.13	-1.00	-0.020	0.00	0.00	2.36	1.24	26.0	37.0	-2.0
P1911 A	ALUM	0.75	Yes	0.750	0.752	2.12	2.13	-1.25	-0.020	0.00	0.00	2.22	1.20	25.0	18.5	-7.0
P1720 A	ALUM	0.75	Yes	0.756	0.754	2.16	2.12	-1.75	-0.020	0.00	0.00	2.25	1.28	39.5	35.0	-6.5
P2313 A	ALUM	0.75	Yes	0.758	0.777	2.16	2.22	-2.25	-0.020	0.00	0.00	1.93	1.09	40.0	39.0	-9.0
P1909 A	ALUM	0.75	Yes	0.749	0.751	2.16	2.14	-1.75	-0.020	0.00	0.00	2.20	1.20	31.5	19.0	-1.0

Table 4.5

PHOTO IDENT: 2 PIX PER SAMPLE		MTR	THICK	SHAV	PLATE THICKNES		MEASUREMENTS FROM MACROPHOTOGRAPHS										
							PLATE THICKNES				WELD REINFORC		WELD WIDTH		FUSION LINE ANGLE		
					A	B	A	B	PEAKIN	MISMATC	CROWN	ROOT	CROWN	ROOT	1/5	2/6	3/7
P2107	A	ALUM	0.75	Yes	0.759	0.748	2.16	2.13	-0.50	-0.010	0.00	0.00	2.06	1.16	32.0	16.5	-7.5
P2106	B	ALUM	0.75	No	0.760	0.751	2.55	2.54	-2.00	-0.010	0.41	0.57	2.31	1.67	21.5	31.0	13.0
P1910	B	ALUM	0.75	No	0.750	0.751	2.12	2.13	-1.25	-0.005	0.41	0.46	2.19	1.21	18.5	14.5	2.5
P2105	A	ALUM	0.75	Yes	0.760	0.747	2.16	2.13	-1.75	-0.005	0.00	0.00	2.04	1.04	29.0	39.0	-12.0
P2313	B	ALUM	0.75	Yes	0.758	0.777	2.18	2.23	-1.25	0.000	0.00	0.00	2.03	1.19	41.0	37.0	-11.0
P1720	B	ALUM	0.75	Yes	0.756	0.754	2.15	2.15	-0.50	0.000	0.00	0.00	2.26	1.29	29.0	24.0	-2.5
P1717	B	ALUM	0.75	No	0.757	0.755	2.13	2.13	-2.00	0.000	0.37	0.55	2.17	1.24	35.5	29.5	2.0
P1707	B	ALUM	0.75	Yes	0.756	0.755	2.18	2.17	-0.50	0.000	0.00	0.00	2.31	1.11	27.0	17.5	-12.0
P1910	A	ALUM	0.75	No	0.750	0.751	2.10	2.13	-1.00	0.000	0.39	0.53	2.25	1.30	20.0	15.5	8.5
P1718	B	ALUM	0.75	No	0.756	0.754	2.15	2.17	-0.25	0.000	0.37	0.56	2.27	1.25	36.0	29.0	6.5
P1719	B	ALUM	0.75	Yes	0.757	0.754	2.15	2.14	0.00	0.000	0.00	0.00	2.29	1.25	35.0	34.0	-9.0
P2109	B	ALUM	0.75	Yes	0.759	0.748	2.17	2.15	-1.50	0.000	0.00	0.00	1.75	1.12	10.0	8.5	-6.5
P2109	A	ALUM	0.75	Yes	0.759	0.748	2.13	2.13	0.00	0.000	0.00	0.00	2.34	1.22	30.5	32.5	-8.0
P2107	B	ALUM	0.75	Yes	0.759	0.748	2.18	2.16	-0.50	0.000	0.00	0.00	1.98	1.18	10.0	37.0	-5.0
P2110	A	ALUM	0.75	No	0.760	0.751	2.57	2.45	-2.50	0.000	0.42	0.49	2.47	1.45	30.5	32.5	2.5
P1706	A	ALUM	0.75	No	0.756	0.756	2.18	2.15	-1.75	0.000	0.35	0.51	2.14	1.23	21.0	18.5	11.0
P1719	A	ALUM	0.75	Yes	0.757	0.754	2.18	2.14	-1.00	0.000	0.00	0.00	2.22	1.30	28.5	34.5	7.0
P2108	B	ALUM	0.75	No	0.761	0.750	2.53	2.52	-1.50	0.005	0.41	0.59	2.35	1.62	40.0	34.0	2.0
P2311	A	ALUM	0.75	Yes	0.758	0.757	2.16	2.23	-0.75	0.005	0.00	0.00	2.03	1.32	37.0	38.0	-3.0
P1913	B	ALUM	0.75	Yes	0.750	0.750	2.16	2.16	-0.75	0.005	0.00	0.00	2.37	1.22	24.5	23.0	-0.5
P2105	B	ALUM	0.75	Yes	0.760	0.747	2.16	2.15	-0.50	0.005	0.00	0.00	1.96	1.32	37.0	34.0	2.0
P2311	B	ALUM	0.75	Yes	0.758	0.757	2.18	2.13	0.00	0.005	0.00	0.00	2.12	1.26	41.5	40.0	-3.0
P1718	A	ALUM	0.75	No	0.756	0.754	2.18	2.17	-0.25	0.010	0.38	0.56	2.16	1.23	26.0	23.0	-1.0
P1912	A	ALUM	0.75	No	0.751	0.751	2.16	2.16	-1.25	0.010	0.39	0.53	2.35	1.30	25.0	22.0	4.0
P1717	A	ALUM	0.75	No	0.757	0.755	2.14	2.13	-1.50	0.010	0.28	0.55	2.23	1.24	30.0	31.5	8.0
P1912	B	ALUM	0.75	No	0.751	0.751	2.15	2.13	-0.75	0.020	0.39	0.48	2.40	1.24	36.5	11.0	1.5
P2110	B	ALUM	0.75	No	0.760	0.751	2.55	2.54	-2.75	0.025	0.38	0.60	2.29	2.54	28.5	26.5	14.0
P2315	A	ALUM	0.75	Yes	0.757	0.778	2.12	2.18	-1.25	0.025	0.00	0.00	1.78	1.15	43.5	2.0	-5.0
P2312	A	ALUM	0.75	No	0.759	0.778	2.17	2.22	-1.00	0.030	0.30	0.51	1.91	1.40	13.5	26.0	0.0
P2312	B	ALUM	0.75	No	0.759	0.778	2.14	2.21	-1.75	0.030	0.30	0.56	1.85	1.35	36.0	6.5	-1.0
P2310	A	ALUM	0.75	No	0.759	0.778	2.17	2.22	-1.50	0.035	0.37	0.54	1.78	1.29	9.0	4.0	-3.0
P2314	B	ALUM	0.75	No	0.760	0.777	2.15	2.19	-1.25	0.035	0.31	0.56	1.79	1.29	36.0	15.5	7.5
P2314	A	ALUM	0.75	No	0.760	0.777	2.15	2.18	-1.00	0.035	0.35	0.55	1.84	1.35	41.5	12.0	10.0
P1908	A	ALUM	0.75	No	0.749	0.752	2.18	2.18	-0.50	0.040	0.41	0.53	2.31	1.23	28.0	10.5	-3.5
P2310	B	ALUM	0.75	No	0.759	0.778	2.15	2.20	-1.25	0.040	0.30	0.53	1.74	1.27	32.0	-0.5	18.5
P2315	B	ALUM	0.75	Yes	0.757	0.778	2.14	2.21	-1.25	0.050	0.00	0.00	1.84	1.33	8.0	44.0	3.5
T5708	A	ALUM	0.75	Yes	0.756	0.758	2.17	2.17	-0.75	-0.015	0.00	0.00	1.18	1.20	19.0	17.0	18.0

Table 4.5

PHOTO IDENT: 2 PIX PER SAMPLE	MTR	THICK	SHAV	PLATE THICKNES		MEASUREMENTS FROM MACROPHOTOGRAPHS										
						PLATE THICKNES				WELD REINFORC		WELD WIDTH		FUSION LINE ANGLE		
				A	B	A	B	PEAKIN	MISMATC	CROWN	ROOT	CROWN	ROOT	1/5	2/6	3/7
T5708 B	ALUM	0.75	Yes	0.756	0.758	2.15	2.15	1.00	0.025	0.00	0.00	1.23	1.10	34.5	19.5	7.0
T5709 A	ALUM	0.75	No	0.757	0.759	2.59	2.60	0.00	-0.015	0.30	0.26	1.60	1.46	32.0	33.0	16.5
T5709 B	ALUM	0.75	No	0.757	0.759	2.61	2.57	0.25	-0.035	0.28	0.26	1.50	1.60	21.5	18.5	28.0
T5710 A	ALUM	0.75	Yes	0.756	0.757	2.15	2.14	0.00	0.000	0.00	0.00	1.20	1.28	24.5	14.0	23.0
T5710 B	ALUM	0.75	Yes	0.756	0.757	2.17	2.17	0.50	0.040	0.00	0.00	1.22	1.23	26.5	22.5	27.5
T5711 A	ALUM	0.75	No	0.757	0.758	2.58	2.61	0.50	0.005	0.25	0.30	1.63	1.50	35.5	32.0	37.0
T5711 B	ALUM	0.75	No	0.757	0.758	2.56	2.59	0.50	0.010	0.26	0.25	1.61	1.59	40.0	27.0	30.0
T5712 A	ALUM	0.75	Yes	0.757	0.757	2.14	2.13	0.00	0.000	0.00	0.00	1.22	1.24	29.5	31.0	34.0
T5712 B	ALUM	0.75	Yes	0.757	0.757	2.15	2.15	0.25	0.015	0.00	0.00	1.26	1.22	23.0	26.0	24.0
T5713 A	ALUM	0.75	No	0.758	0.759	2.55	2.56	-0.25	-0.015	0.28	0.27	1.60	1.55	43.0	21.0	18.5
T5713 B	ALUM	0.75	No	0.758	0.759	2.59	2.59	-0.25	-0.005	0.29	0.28	1.88	1.62	28.5	32.0	29.5
T5812 A	ALUM	0.75	No	0.752	0.755	2.12	2.13	0.25	-0.315	0.25	0.33	1.30	1.29	18.0	38.5	36.0
T5812 B	ALUM	0.75	No	0.752	0.755	2.17	2.17	0.75	-0.330	0.26	0.23	1.30	1.25	14.0	32.0	31.0
T5813 A	ALUM	0.75	Yes	0.752	0.755	2.16	2.17	1.00	-0.350	0.00	0.00	1.35	1.31	25.0	34.0	30.5
T5813 B	ALUM	0.75	Yes	0.752	0.755	2.14	2.18	0.00	-0.340	0.00	0.00	1.27	1.14	23.0	30.5	20.0
T5814 A	ALUM	0.75	No	0.752	0.755	2.15	2.16	0.25	-0.325	0.25	0.25	1.26	1.33	13.5	27.0	38.5
T5814 B	ALUM	0.75	No	0.752	0.755	2.14	2.16	0.50	-0.320	0.23	0.23	1.28	1.28	13.5	31.5	37.0
T5815 A	ALUM	0.75	Yes	0.750	0.754	2.12	2.13	0.75	-0.435	0.00	0.00	1.37	1.26	9.0	20.0	35.0
T5815 B	ALUM	0.75	Yes	0.750	0.754	2.14	2.12	0.00	-0.350	0.00	0.00	1.22	1.16	20.0	21.0	25.5
T5816 A	ALUM	0.75	No	0.751	0.755	2.16	2.16	-0.25	-0.285	0.26	0.26	1.30	1.34	21.0	30.0	38.0
T5816 B	ALUM	0.75	No	0.751	0.755	2.17	2.17	0.50	-0.310	0.24	0.24	1.32	1.37	21.0	33.0	27.0
T5817 A	ALUM	0.75	Yes	0.750	0.755	2.17	2.16	0.50	-0.310	0.00	0.00	1.27	1.22	11.0	27.0	28.0
T5817 B	ALUM	0.75	Yes	0.750	0.755	2.14	2.16	0.25	-0.280	0.00	0.00	1.34	1.40	29.5	32.0	38.0
T5910 A	ALUM	0.75	Yes	0.783	0.770	2.24	2.18	-11.75	-0.040	0.00	0.00	1.42	0.74	16.0	23.0	-9.0
T5910 B	ALUM	0.75	Yes	0.783	0.770	2.23	2.17	-10.25	-0.075	0.00	0.00	1.37	0.64	13.0	27.0	-2.0
T5911 A	ALUM	0.75	No	0.783	0.771	2.24	2.20	-10.25	-0.015	0.18	0.09	1.44	0.67	21.0	28.5	-3.0
T5911 B	ALUM	0.75	No	0.783	0.771	2.25	2.18	-10.00	-0.020	0.18	0.09	1.45	0.69	38.0	24.0	-4.0
T5912 A	ALUM	0.75	Yes	0.783	0.770	2.25	2.21	-12.00	-0.020	0.00	0.00	1.31	0.61	17.0	15.0	-4.0
T5912 B	ALUM	0.75	Yes	0.783	0.770	2.22	2.22	-10.50	-0.025	0.00	0.00	1.32	0.55	12.0	10.0	-2.0
T5913 A	ALUM	0.75	No	0.783	0.770	2.23	2.19	-10.25	-0.020	0.17	0.10	1.52	0.68	32.0	43.0	0.0
T5913 B	ALUM	0.75	No	0.783	0.770	2.23	2.21	-10.75	0.000	0.16	0.09	1.47	0.69	26.0	44.0	11.0
T5914 A	ALUM	0.75	Yes	0.783	0.770	2.24	2.18	-10.50	-0.010	0.00	0.00	1.33	0.64	19.0	10.5	-5.5
T5914 B	ALUM	0.75	Yes	0.783	0.770	2.20	2.18	-11.25	0.010	0.00	0.00	1.40	0.70	13.0	18.0	-5.0
T5915 A	ALUM	0.75	No	0.783	0.769	2.25	2.19	-10.75	-0.005	0.16	0.07	1.48	0.73	23.0	30.0	-2.5
T5915 B	ALUM	0.75	No	0.783	0.769	2.20	2.20	-10.25	0.010	0.09	0.06	1.50	0.64	28.0	31.0	-3.0

Table 4.5

PHOTO IDENT: 2 PIX PER SAMPLE	MTR	THICK	SHAV	PLATE THICKNES		MEASUREMENTS FROM MACROPHOTOGRAPHS										
						PLATE THICKNES				WELD REINFORC		WELD WIDTH		FUSION LINE ANGLE		
				A	B	A	B	PEAKIN	MISMATC	CROWN	ROOT	CROWN	ROOT	1/5	2/6	3/7
T6108 A	ALUM	0.75	No	0.750	0.754	2.15	2.15	0.00	-0.015	0.21	0.22	1.05	1.25	17.5	20.5	28.0
T6108 B	ALUM	0.75	No	0.750	0.754	2.13	2.15	0.00	0.005	0.21	0.21	1.13	1.18	29.0	15.0	19.0
T6109 A	ALUM	0.75	Yes	0.751	0.753	2.13	2.13	-0.50	0.000	0.00	0.00	0.91	1.05	8.0	7.0	19.0
T6109 B	ALUM	0.75	Yes	0.751	0.753	2.14	2.14	0.25	0.000	0.00	0.00	0.89	1.02	6.0	7.0	17.0
T6110 A	ALUM	0.75	No	0.750	0.754	2.14	2.15	0.00	-0.015	0.21	0.25	1.15	1.26	26.5	22.0	33.0
T6110 B	ALUM	0.75	No	0.750	0.754	2.15	2.18	0.00	-0.010	0.23	0.23	1.15	1.15	27.0	30.5	22.5
T6111 A	ALUM	0.75	Yes	0.750	0.753	2.14	2.13	0.00	0.000	0.00	0.00	1.04	1.07	21.0	16.0	16.5
T6111 B	ALUM	0.75	Yes	0.750	0.753	2.14	2.17	0.00	0.015	0.00	0.00	0.96	1.04	15.0	6.5	7.0
T6112 A	ALUM	0.75	No	0.750	0.754	2.15	2.15	0.00	0.000	0.22	0.23	1.08	1.11	20.0	9.5	18.0
T6112 B	ALUM	0.75	No	0.750	0.754	2.15	2.18	0.25	0.000	0.22	0.22	1.21	1.28	31.0	21.0	30.0
T6113 A	ALUM	0.75	Yes	0.750	0.753	2.10	2.13	0.25	0.000	0.02	0.00	1.04	1.04	22.5	15.0	9.0
T6113 B	ALUM	0.75	Yes	0.750	0.753	2.10	2.15	0.50	-0.010	0.00	0.00	0.95	1.11	13.0	9.0	22.0
T6209 A	ALUM	0.75	No	0.755	0.759	2.15	2.19	0.25	-0.280	0.15	0.12	1.00	1.13	13.0	14.5	21.0
T6209 B	ALUM	0.75	No	0.755	0.759	2.18	2.17	0.25	-0.265	0.19	0.14	1.19	1.10	16.0	25.0	26.5
T6210 A	ALUM	0.75	Yes	0.756	0.758	2.14	2.07	-0.50	-0.295	0.00	0.00	1.03	0.88	-5.0	5.5	0.0
T6210 B	ALUM	0.75	Yes	0.756	0.758	2.15	2.17	0.50	-0.330	0.00	0.00	0.94	0.97	-13.0	-3.5	13.5
T6211 A	ALUM	0.75	No	0.755	0.759	2.16	2.16	0.50	-0.245	0.22	0.16	1.24	1.14	14.0	22.0	32.0
T6211 B	ALUM	0.75	No	0.755	0.759	2.16	2.15	0.50	-0.270	0.17	0.15	1.06	1.07	13.5	16.0	29.5
T6212 A	ALUM	0.75	Yes	0.755	0.759	2.18	2.19	0.75	-0.300	0.00	0.00	0.98	0.92	-11.0	2.0	4.5
T6212 B	ALUM	0.75	Yes	0.755	0.759	2.15	2.17	0.00	-0.290	0.00	0.00	1.33	1.03	18.5	4.0	6.5
T6213 A	ALUM	0.75	No	0.755	0.759	2.15	2.15	0.50	-0.255	0.18	0.16	1.06	1.04	19.0	15.5	15.5
T6213 B	ALUM	0.75	No	0.755	0.759	2.15	2.16	1.00	-0.255	0.16	0.13	1.10	1.05	7.0	24.0	30.0
T6214 A	ALUM	0.75	Yes	0.755	0.761	2.17	2.16	0.25	-0.290	0.00	0.00	1.02	0.92	-1.0	-3.0	6.0
T6214 B	ALUM	0.75	Yes	0.755	0.761	2.16	2.17	0.50	-0.275	0.00	0.00	0.97	0.94	-13.0	-1.5	11.5
T6314 A	ALUM	0.75	Yes	0.755	0.755	2.20	2.20	-9.75	-0.030	0.00	0.00	1.19	0.69	18.0	23.0	-1.0
T6314 B	ALUM	0.75	Yes	0.755	0.755	2.12	2.16	-10.25	0.010	0.00	0.00	1.20	0.69	-6.5	23.5	-2.0
T6315 A	ALUM	0.75	No	0.753	0.755	2.17	2.17	-9.25	-0.005	0.13	0.11	1.12	0.81	28.0	23.0	2.5
T6315 B	ALUM	0.75	No	0.753	0.755	2.13	2.16	-9.50	-0.005	0.18	0.09	1.17	0.77	31.0	23.5	0.0
T6316 A	ALUM	0.75	Yes	0.753	0.755	2.14	2.19	-9.25	-0.015	0.00	0.00	1.12	0.74	18.0	28.5	0.5
T6316 B	ALUM	0.75	Yes	0.753	0.755	2.12	2.13	-9.75	0.020	0.00	0.00	1.04	0.74	11.5	24.0	0.5
T6317 A	ALUM	0.75	No	0.753	0.756	2.15	2.19	-9.50	-0.015	0.18	0.09	1.14	0.77	36.0	20.0	8.0
T6317 B	ALUM	0.75	No	0.753	0.756	2.14	2.16	-9.25	0.005	0.17	0.09	1.16	0.78	33.0	21.0	12.0
T6318 A	ALUM	0.75	Yes	0.753	0.756	2.15	2.10	-9.75	-0.035	0.00	0.00	1.11	0.77	29.0	25.0	-2.0
T6318 B	ALUM	0.75	Yes	0.753	0.756	2.16	2.16	-9.25	0.015	0.00	0.00	1.15	0.76	34.0	27.5	2.0
T6319 A	ALUM	0.75	No	0.753	0.756	2.16	2.16	-9.25	0.000	0.17	0.09	1.15	0.81	24.5	23.5	3.5
T6319 B	ALUM	0.75	No	0.753	0.756	2.14	2.14	-9.00	0.010	0.15	0.08	1.16	0.86	30.0	20.0	3.0

Table 4.5

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PHOTO IDENT: SAMPLE	2 PIX PER :S 4/8	MAX CROW DEPTH	:RN/ROO' INTERSE WIDTH	PHOTO MAG.	MIS-MATCH	WELD REINFORCE CROWN	WELD REINFORCE ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	:RN/ROO' INTERSE WIDTH	UTS (ksi)	0.20% Y.S. (ksi)	% Elong
		ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO M										TENSILE TEST RESUL		
P2207 A	-6.5	0.43	1.58	2.785	-0.147	0.000	0.000	0.574	0.478	0.154	0.567	36.8	14.0	6.9
P1816 B	0.0	0.97	1.62	2.854	-0.142	-0.007	-0.004	0.876	0.547	0.340	0.568	34.5	14.5	6.0
P2207 B	-3.0	0.46	1.65	2.865	-0.138	0.000	0.000	0.586	0.510	0.161	0.576	36.8	14.0	6.9
P2212 A	2.5	0.68	1.97	3.393	-0.137	0.088	0.177	0.631	0.522	0.200	0.581	27.7	15.9	4.0
P2211 A	-2.0	0.54	1.67	2.805	-0.135	0.000	0.000	0.595	0.520	0.193	0.595	38.0	17.7	7.5
P2208 A	2.5	0.60	1.94	3.404	-0.131	0.085	0.179	0.617	0.520	0.176	0.570	27.4	14.3	3.3
P1816 A	4.0	0.98	1.60	2.900	-0.129	-0.014	0.000	0.828	0.500	0.338	0.552	34.5	14.5	6.0
P1810 B	-5.0	1.00	1.56	2.843	-0.128	0.025	0.000	0.784	0.457	0.352	0.549	36.5	0.0	5.9
P2209 B	-5.0	0.56	1.70	2.906	-0.127	0.000	0.000	0.585	0.502	0.193	0.585	38.0	15.8	7.9
P2209 A	-4.0	0.53	1.67	2.814	-0.119	0.000	0.000	0.594	0.476	0.188	0.594	38.0	15.8	7.9
P1810 A	-5.5	0.89	1.62	2.856	-0.117	0.000	0.000	0.854	0.438	0.312	0.567	36.5	0.0	5.9
P1815 A	-6.0	1.05	1.57	2.845	-0.116	-0.007	0.011	0.851	0.457	0.369	0.552	37.1	16.3	5.7
P2210 B	1.0	0.61	1.84	3.388	-0.115	0.086	0.162	0.637	0.502	0.180	0.543	27.9	16.2	2.8
P1815 B	-2.0	0.89	1.65	2.826	-0.115	0.000	0.000	0.899	0.478	0.315	0.584	37.1	16.3	5.7
P2208 B	8.0	0.69	1.86	3.397	-0.113	0.082	0.185	0.618	0.515	0.203	0.548	27.4	14.3	3.3
P2211 B	-4.5	0.47	1.83	2.825	-0.113	0.000	0.000	0.644	0.520	0.166	0.648	38.0	17.7	7.5
P2210 A	-3.0	0.65	1.93	3.362	-0.113	0.080	0.164	0.619	0.506	0.193	0.574	27.9	16.2	2.8
P1819 A	-5.0	1.18	2.03	3.405	-0.112	0.109	0.220	0.734	0.499	0.347	0.596	28.6	19.0	2.2
P1818 A	0.0	1.32	1.98	3.396	-0.110	0.097	0.221	0.716	0.506	0.389	0.583	28.5	15.3	2.6
P1818 B	20.0	1.18	1.92	3.383	-0.109	0.115	0.204	0.730	0.532	0.349	0.568	28.5	15.3	2.6
P1820 A	-2.0	1.19	1.92	3.394	-0.106	0.115	0.206	0.787	0.510	0.351	0.566	28.2	17.5	2.3
P1820 B	1.5	1.21	1.87	3.394	-0.103	0.115	0.200	0.757	0.527	0.357	0.551	28.2	17.5	2.3
P2212 B	-11.5	0.65	1.96	3.386	-0.102	0.063	0.183	0.620	0.520	0.192	0.579	27.7	15.9	4.0
P1819 B	-2.0	1.10	1.91	3.353	-0.101	0.119	0.194	0.790	0.507	0.328	0.570	28.6	19.0	2.2
P2106 A	13.5	0.59	2.03	3.415	-0.022	0.114	0.152	0.668	0.428	0.173	0.594	36.7	18.4	3.7
P2108 A	-1.0	0.63	2.01	3.369	-0.019	0.110	0.175	0.683	0.736	0.187	0.597	37.6	20.3	3.5
P1913 A	2.5	1.09	1.61	2.840	-0.012	0.000	0.000	0.838	0.423	0.384	0.567	39.6	15.4	11.0
P1706 B	8.0	0.90	1.60	2.824	-0.009	0.117	0.177	0.783	0.414	0.319	0.567	37.1	15.8	5.2
P1707 A	-8.0	0.88	1.65	2.826	-0.009	0.000	0.000	0.768	0.382	0.311	0.584	38.8	17.6	7.0
P1908 B	-2.5	1.11	1.62	2.838	-0.009	0.137	0.187	0.817	0.486	0.391	0.571	35.7	17.1	3.8
P1911 B	-2.0	1.08	1.54	2.850	-0.009	0.000	0.000	0.793	0.439	0.379	0.540	39.6	15.9	10.8
P1909 B	-3.5	1.05	1.53	2.827	-0.007	0.000	0.000	0.835	0.439	0.371	0.541	39.2	13.9	10.3
P1911 A	0.0	1.01	1.57	2.830	-0.007	0.000	0.000	0.785	0.424	0.357	0.555	39.6	15.9	10.8
P1720 A	-5.0	1.21	1.66	2.834	-0.007	0.000	0.000	0.794	0.452	0.427	0.586	39.8	15.3	10.7
P2313 A	-12.0	0.53	1.57	2.853	-0.007	0.000	0.000	0.676	0.382	0.186	0.550	40.1	18.9	9.4
P1909 A	1.5	1.02	1.53	2.867	-0.007	0.000	0.000	0.767	0.419	0.356	0.534	39.2	13.9	10.3

Table 4.5

PHOTO IDENT: 2 PIX PER SAMPLE		:S 4/8	MAX CROW DEPTH	:RN/ROO' INTERSE WIDTH	PHOTO MAG.	MIS-MATCH	WELD REINFORCE CROWN	WELD REINFORCE ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	:RN/ROO' INTERSE WIDTH	UTS (ksi)	0.20% Y.S. (ksi)	% Elong
					ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO M								TENSILE TEST RESUL		
P2107	A	-3.0	0.53	1.89	2.847	-0.004	0.000	0.000	0.724	0.407	0.186	0.664	39.9	18.8	9.0
P2106	B	9.0	0.61	2.07	3.369	-0.003	0.122	0.169	0.686	0.496	0.181	0.614	36.7	18.4	3.7
P1910	B	-4.0	1.19	1.55	2.831	-0.002	0.145	0.162	0.773	0.427	0.420	0.547	37.3	16.7	5.5
P2105	A	-12.5	0.44	1.69	2.847	-0.002	0.000	0.000	0.717	0.365	0.155	0.594	39.9	19.5	8.7
P2313	B	-14.0	0.59	1.70	2.873	0.000	0.000	0.000	0.707	0.414	0.205	0.592	40.1	18.9	9.4
P1720	B	-7.0	1.28	1.63	2.848	0.000	0.000	0.000	0.794	0.453	0.449	0.572	39.8	15.3	10.7
P1717	B	5.5	1.19	1.61	2.817	0.000	0.131	0.195	0.770	0.440	0.422	0.571	37.2	16.0	5.9
P1707	B	-12.0	0.87	1.63	2.879	0.000	0.000	0.000	0.802	0.386	0.302	0.566	38.8	17.6	7.0
P1910	A	5.5	0.95	1.56	2.818	0.000	0.138	0.188	0.798	0.461	0.337	0.554	37.3	16.7	5.5
P1718	B	-3.0	1.22	1.59	2.861	0.000	0.129	0.196	0.793	0.437	0.426	0.556	36.8	14.5	6.0
P1719	B	-5.5	1.30	1.66	2.839	0.000	0.000	0.000	0.807	0.440	0.458	0.585	38.4	17.5	9.8
P2109	B	-4.0	0.55	1.74	2.867	0.000	0.000	0.000	0.610	0.391	0.192	0.607	38.7	17.6	9.0
P2109	A	-3.5	0.57	1.80	2.827	0.000	0.000	0.000	0.828	0.432	0.202	0.637	38.7	17.6	9.0
P2107	B	-12.5	0.54	1.76	2.880	0.000	0.000	0.000	0.688	0.410	0.188	0.611	39.9	18.8	9.0
P2110	A	7.0	0.57	2.03	3.322	0.000	0.126	0.147	0.743	0.436	0.172	0.611	35.6	14.6	4.0
P1706	A	8.5	0.85	1.56	2.864	0.000	0.122	0.178	0.747	0.430	0.297	0.545	37.1	15.8	5.2
P1719	A	-8.0	1.19	1.63	2.859	0.000	0.000	0.000	0.776	0.455	0.416	0.570	38.4	17.5	9.8
P2108	B	9.0	0.60	1.96	3.342	0.001	0.123	0.177	0.703	0.485	0.180	0.586	37.6	20.3	3.5
P2311	A	2.0	0.55	1.66	2.898	0.002	0.000	0.000	0.701	0.456	0.190	0.573	40.7	19.7	8.0
P1913	B	-7.5	0.98	1.61	2.880	0.002	0.000	0.000	0.823	0.424	0.340	0.559	39.6	15.4	11.0
P2105	B	0.0	0.47	1.62	2.860	0.002	0.000	0.000	0.685	0.462	0.164	0.566	39.9	19.5	8.7
P2311	B	-6.0	0.54	1.69	2.845	0.002	0.000	0.000	0.745	0.443	0.190	0.594	40.7	19.7	8.0
P1718	A	7.0	1.17	1.66	2.881	0.003	0.132	0.194	0.750	0.427	0.406	0.576	36.8	14.5	6.0
P1912	A	3.5	1.12	1.62	2.876	0.003	0.136	0.184	0.817	0.452	0.389	0.563	37.0	16.1	5.4
P1717	A	4.0	1.19	1.54	2.824	0.004	0.099	0.195	0.790	0.439	0.421	0.545	37.2	16.0	5.9
P1912	B	0.0	1.11	1.59	2.850	0.007	0.137	0.168	0.842	0.435	0.390	0.558	37.0	16.1	5.4
P2110	B	10.0	0.60	1.95	3.369	0.007	0.113	0.178	0.680	0.754	0.178	0.579	35.6	14.6	4.0
P2315	A	-6.5	0.61	1.69	2.801	0.009	0.000	0.000	0.635	0.411	0.218	0.603	41.0	19.1	7.8
P2312	A	2.0	0.53	1.82	2.856	0.011	0.105	0.179	0.669	0.490	0.186	0.637	35.7	18.9	3.5
P2312	B	3.5	0.57	1.68	2.830	0.011	0.106	0.198	0.654	0.477	0.201	0.594	35.7	18.9	3.5
P2310	A	-2.5	0.50	1.76	2.856	0.012	0.130	0.189	0.623	0.452	0.175	0.616	35.2	16.4	3.7
P2314	B	0.0	0.55	1.62	2.824	0.012	0.110	0.198	0.634	0.457	0.195	0.574	34.4	14.1	2.3
P2314	A	3.5	0.50	1.63	2.817	0.012	0.124	0.195	0.653	0.479	0.177	0.579	34.4	14.1	2.3
P1908	A	1.0	1.05	1.57	2.905	0.014	0.141	0.182	0.795	0.423	0.361	0.540	35.7	17.1	3.8
P2310	B	10.0	0.55	1.60	2.830	0.014	0.106	0.187	0.615	0.449	0.194	0.565	35.2	16.4	3.7
P2315	B	0.0	0.60	1.70	2.834	0.018	0.000	0.000	0.649	0.469	0.212	0.600	41.0	19.1	7.8
T5708	A	8.0	N/A	N/A	2.867	-0.005	0.000	0.000	0.412	0.419	N/A	N/A	42.0	20.8	6.8

Table 4.5

PHOTO IDENT: 2 PIX PER SAMPLE		:S 4/8	MAX CROW. DEPTH	:RN/ROO' INTERSE WIDTH	ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO M PHOTO MAG.	MIS-MATCH	WELD REINFORCE CROWN	ROOT	WELD WIDTH CROWN	ROOT	CROWN DEPTH	:RN/ROO' INTERSE WIDTH	TENSILE TEST RESUL UTS (ksi)	0.20% Y.S. (ksi)	% Elong
T5708	B	11.0	N/A	N/A	2.840	0.009	0.000	0.000	0.433	0.387	N/A	N/A	42.0	20.8	6.8
T5709	A	18.0	N/A	N/A	3.423	-0.004	0.088	0.076	0.467	0.426	N/A	N/A	44.5	21.6	7.1
T5709	B	23.0	N/A	N/A	3.417	-0.010	0.082	0.076	0.439	0.468	N/A	N/A	44.5	21.6	7.1
T5710	A	12.5	N/A	N/A	2.835	0.000	0.000	0.000	0.423	0.451	N/A	N/A	42.6	19.9	7.3
T5710	B	26.5	N/A	N/A	2.868	0.014	0.000	0.000	0.425	0.429	N/A	N/A	42.6	19.9	7.3
T5711	A	23.0	N/A	N/A	3.426	0.001	0.073	0.088	0.476	0.438	N/A	N/A	44.4	25.1	7.0
T5711	B	40.0	N/A	N/A	3.399	0.003	0.076	0.074	0.474	0.468	N/A	N/A	44.4	25.1	7.0
T5712	A	20.0	N/A	N/A	2.820	0.000	0.000	0.000	0.433	0.440	N/A	N/A	41.9	20.1	7.3
T5712	B	14.0	N/A	N/A	2.840	0.005	0.000	0.000	0.444	0.430	N/A	N/A	41.9	20.1	7.3
T5713	A	23.0	N/A	N/A	3.368	-0.004	0.083	0.080	0.475	0.460	N/A	N/A	44.5	24.2	6.9
T5713	B	26.5	N/A	N/A	3.415	-0.001	0.085	0.082	0.551	0.474	N/A	N/A	44.5	24.2	6.9
T5812	A	30.0	N/A	N/A	2.820	-0.112	0.089	0.117	0.461	0.457	N/A	N/A	37.2	21.2	4.2
T5812	B	6.0	N/A	N/A	2.880	-0.115	0.090	0.080	0.451	0.434	N/A	N/A	37.2	21.2	4.2
T5813	A	18.0	N/A	N/A	2.873	-0.122	0.000	0.000	0.470	0.456	N/A	N/A	40.1	19.9	6.0
T5813	B	8.0	N/A	N/A	2.867	-0.119	0.000	0.000	0.443	0.398	N/A	N/A	40.1	19.9	6.0
T5814	A	13.5	N/A	N/A	2.860	-0.114	0.087	0.087	0.441	0.465	N/A	N/A	36.6	23.5	4.2
T5814	B	10.0	N/A	N/A	2.853	-0.112	0.081	0.081	0.449	0.449	N/A	N/A	36.6	23.5	4.2
T5815	A	6.5	N/A	N/A	2.826	-0.154	0.000	0.000	0.485	0.446	N/A	N/A	37.8	18.3	5.7
T5815	B	6.5	N/A	N/A	2.832	-0.124	0.000	0.000	0.431	0.410	N/A	N/A	37.8	18.3	5.7
T5816	A	14.5	N/A	N/A	2.869	-0.099	0.091	0.091	0.453	0.467	N/A	N/A	36.9	24.1	3.9
T5816	B	18.0	N/A	N/A	2.882	-0.108	0.083	0.083	0.458	0.475	N/A	N/A	36.9	24.1	3.9
T5817	A	4.0	N/A	N/A	2.877	-0.108	0.000	0.000	0.441	0.424	N/A	N/A	41.2	22.4	5.7
T5817	B	27.0	N/A	N/A	2.857	-0.098	0.000	0.000	0.469	0.490	N/A	N/A	41.2	22.4	5.7
T5910	A	-7.0	N/A	N/A	2.846	-0.014	0.000	0.000	0.499	0.260	N/A	N/A	34.2	26.8	4.8
T5910	B	-5.0	N/A	N/A	2.833	-0.026	0.000	0.000	0.484	0.226	N/A	N/A	34.2	26.8	4.8
T5911	A	-3.0	N/A	N/A	2.857	-0.005	0.063	0.032	0.504	0.235	N/A	N/A	25.3	2.8	2.6
T5911	B	0.0	N/A	N/A	2.851	-0.007	0.063	0.032	0.509	0.242	N/A	N/A	25.3	2.8	2.6
T5912	A	-8.0	N/A	N/A	2.872	-0.007	0.000	0.000	0.456	0.212	N/A	N/A	36.4	27.1	5.2
T5912	B	-7.0	N/A	N/A	2.859	-0.009	0.000	0.000	0.462	0.192	N/A	N/A	36.4	27.1	5.2
T5913	A	-4.5	N/A	N/A	2.846	-0.007	0.060	0.035	0.534	0.239	N/A	N/A	25.5	0.0	3.1
T5913	B	11.0	N/A	N/A	2.859	0.000	0.056	0.031	0.514	0.241	N/A	N/A	25.5	0.0	3.1
T5914	A	-4.0	N/A	N/A	2.846	-0.004	0.000	0.000	0.467	0.225	N/A	N/A	37.7	0.0	4.6
T5914	B	-7.0	N/A	N/A	2.820	0.004	0.000	0.000	0.496	0.248	N/A	N/A	37.7	0.0	4.6
T5915	A	0.0	N/A	N/A	2.861	-0.002	0.056	0.024	0.510	0.255	N/A	N/A	27.7	18.3	3.3
T5915	B	-6.5	N/A	N/A	2.835	0.004	0.032	0.021	0.529	0.226	N/A	N/A	27.7	18.3	3.3

Table 4.5

PHOTO IDENT: 2 PIX PER SAMPLE		:ES 4/8	MAX CROW DEPTH	:RN/ROO INTERSE WIDTH	PHOTO MAG.	MIS-MATCH	WELD REINFORCE CROWN	WELD REINFORCE ROOT	WELD WIDTH CROWN	WELD WIDTH ROOT	CROWN DEPTH	:RN/ROO INTERSE WIDTH	UTS (ksi)	0.20% Y.S. (ksi)	% Elong
					ACTUAL DIMENSIONS (PHOTO MEASUREMENTS CORRECTED FOR PHOTO M								TENSILE TEST RESUL		
T6108	A	29.0	N/A	N/A	2.859	-0.005	0.073	0.077	0.387	0.437	N/A	N/A	44.3	22.7	6.5
T6108	B	17.5	N/A	N/A	2.846	0.002	0.074	0.074	0.397	0.415	N/A	N/A	44.3	22.7	6.5
T6109	A	17.0	N/A	N/A	2.832	0.000	0.000	0.000	0.321	0.371	N/A	N/A	43.4	19.4	7.4
T6109	B	10.0	N/A	N/A	2.846	0.000	0.000	0.000	0.313	0.358	N/A	N/A	43.4	19.4	7.4
T6110	A	20.5	N/A	N/A	2.852	-0.005	0.074	0.088	0.403	0.442	N/A	N/A	44.9	22.0	2.3
T6110	B	27.5	N/A	N/A	2.879	-0.003	0.080	0.080	0.399	0.399	N/A	N/A	44.9	22.0	2.3
T6111	A	18.0	N/A	N/A	2.841	0.000	0.000	0.000	0.366	0.377	N/A	N/A	45.1	21.8	6.8
T6111	B	12.0	N/A	N/A	2.868	0.005	0.000	0.000	0.335	0.363	N/A	N/A	45.1	21.8	6.8
T6112	A	16.5	N/A	N/A	2.859	0.000	0.077	0.080	0.378	0.388	N/A	N/A	45.2	23.0	7.0
T6112	B	31.0	N/A	N/A	2.879	0.000	0.076	0.076	0.420	0.445	N/A	N/A	45.2	23.0	7.0
T6113	A	9.0	N/A	N/A	2.814	0.000	0.007	0.000	0.370	0.370	N/A	N/A	43.4	19.9	6.0
T6113	B	18.0	N/A	N/A	2.828	-0.004	0.000	0.000	0.336	0.393	N/A	N/A	43.4	19.9	6.0
T6209	A	19.0	N/A	N/A	2.867	-0.098	0.052	0.042	0.349	0.394	N/A	N/A	40.7	22.5	5.3
T6209	B	17.0	N/A	N/A	2.873	-0.092	0.066	0.049	0.414	0.383	N/A	N/A	40.7	22.5	5.3
T6210	A	0.0	N/A	N/A	2.781	-0.106	0.000	0.000	0.370	0.316	N/A	N/A	40.4	21.3	6.0
T6210	B	0.0	N/A	N/A	2.853	-0.116	0.000	0.000	0.329	0.340	N/A	N/A	40.4	21.3	6.0
T6211	A	23.0	N/A	N/A	2.853	-0.086	0.077	0.056	0.435	0.400	N/A	N/A	41.0	20.1	5.3
T6211	B	14.5	N/A	N/A	2.847	-0.095	0.060	0.053	0.372	0.376	N/A	N/A	41.0	20.1	5.3
T6212	A	3.5	N/A	N/A	2.886	-0.104	0.000	0.000	0.340	0.319	N/A	N/A	42.5	22.3	6.0
T6212	B	7.0	N/A	N/A	2.853	-0.102	0.000	0.000	0.466	0.361	N/A	N/A	42.5	22.3	6.0
T6213	A	33.0	N/A	N/A	2.840	-0.090	0.063	0.056	0.373	0.366	N/A	N/A	41.0	22.0	4.6
T6213	B	15.5	N/A	N/A	2.847	-0.090	0.056	0.046	0.386	0.369	N/A	N/A	41.0	22.0	4.6
T6214	A	5.0	N/A	N/A	2.856	-0.102	0.000	0.000	0.357	0.322	N/A	N/A	41.6	19.8	5.5
T6214	B	2.5	N/A	N/A	2.856	-0.096	0.000	0.000	0.340	0.329	N/A	N/A	41.6	19.8	5.5
T6314	A	-7.0	N/A	N/A	2.914	-0.010	0.000	0.000	0.408	0.237	N/A	N/A	41.5	0.0	5.2
T6314	B	-3.0	N/A	N/A	2.834	0.004	0.000	0.000	0.423	0.243	N/A	N/A	41.5	0.0	5.2
T6315	A	5.5	N/A	N/A	2.878	-0.002	0.045	0.038	0.389	0.281	N/A	N/A	29.0	17.1	5.0
T6315	B	-2.0	N/A	N/A	2.845	-0.002	0.063	0.032	0.411	0.271	N/A	N/A	29.0	17.1	5.0
T6316	A	0.0	N/A	N/A	2.871	-0.005	0.000	0.000	0.390	0.258	N/A	N/A	41.1	0.0	5.3
T6316	B	-3.5	N/A	N/A	2.818	0.007	0.000	0.000	0.369	0.263	N/A	N/A	41.1	0.0	5.3
T6317	A	-3.0	N/A	N/A	2.876	-0.005	0.063	0.031	0.396	0.268	N/A	N/A	31.3	21.2	4.2
T6317	B	9.0	N/A	N/A	2.850	0.002	0.060	0.032	0.407	0.274	N/A	N/A	31.3	21.2	4.2
T6318	A	-4.0	N/A	N/A	2.816	-0.012	0.000	0.000	0.394	0.273	N/A	N/A	41.5	0.0	6.1
T6318	B	-1.0	N/A	N/A	2.863	0.005	0.000	0.000	0.402	0.265	N/A	N/A	41.5	0.0	6.1
T6319	A	1.0	N/A	N/A	2.863	0.000	0.059	0.031	0.402	0.283	N/A	N/A	32.6	0.0	3.4
T6319	B	5.0	N/A	N/A	2.836	0.004	0.053	0.028	0.409	0.303	N/A	N/A	32.6	0.0	3.4

Table 4.5

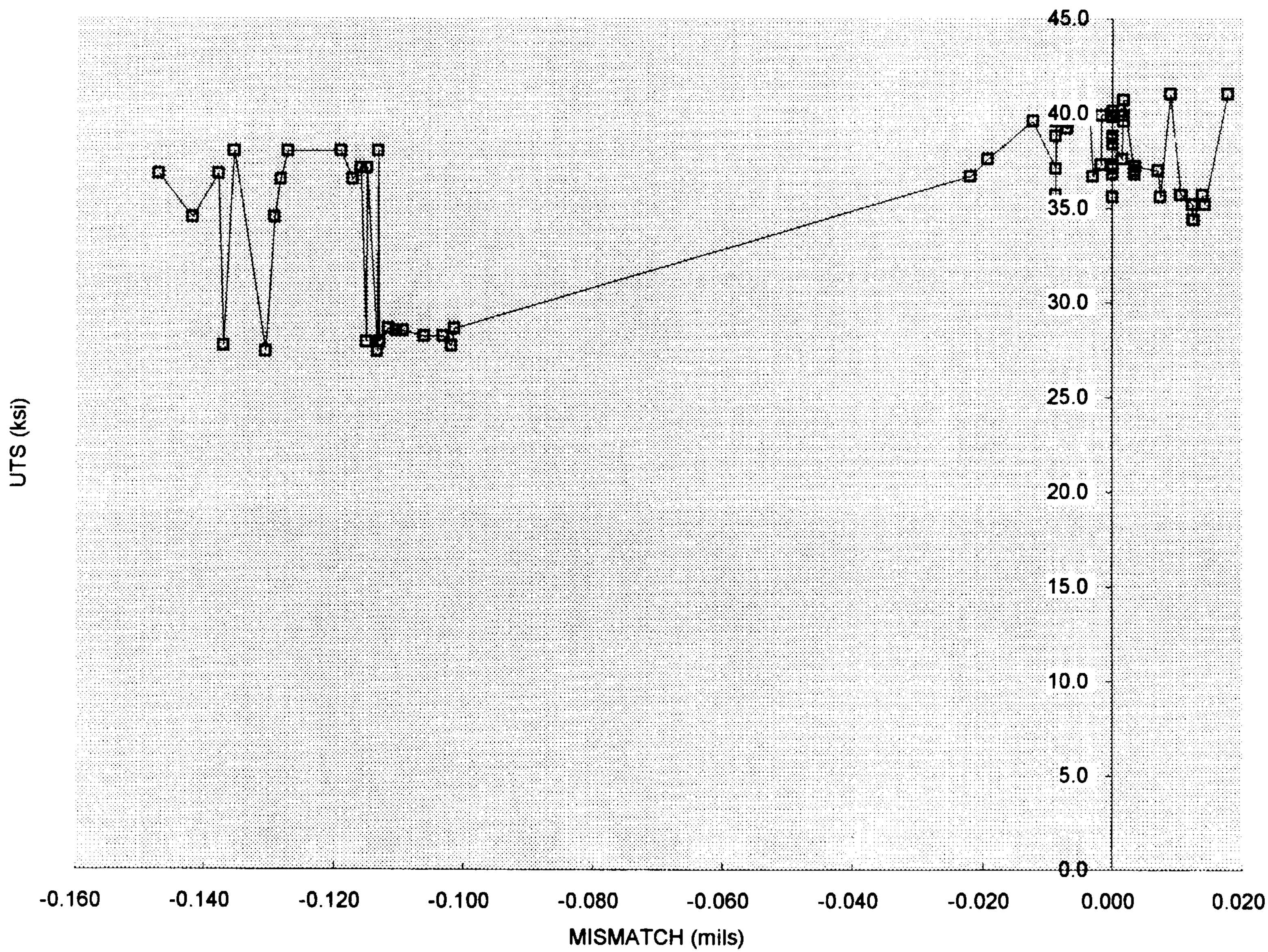

Table 4.5 Graph

5.0 Microstructural Evaluation Of Fracture Origins

Scanning Electron Microscopy (SEM) was performed on three 2219-T6 aluminum weld specimens tensile tested during the prior investigation. Fracture surfaces were examined in an attempt to locate the fracture origins. Individual fracture initiation sites were not able to be determined, however a general fracture front direction was discernible.

Microhardness traverses were done on the aluminum specimens. The data and the associated graph is included in table 5.1.

Hardness Data for 2219-T6 Aluminum

HV Spacing (L to R)	P2319 Crown	P2319 Center	P2319 Root	P2320 Crown	P2320 Center	P2320 Root
0.00	119.0	115.0	115.0	118.0	117.0	115.0
0.05	115.0	113.0	112.0	115.0	116.0	116.0
0.10	116.0	109.0	110.0	112.0	111.0	110.0
0.15	113.0	109.0	108.0	107.0	109.0	109.0
0.20	107.0	106.0	104.0	102.0	106.0	105.0
0.25	102.0	100.0	102.0	99.9	101.0	101.0
0.30	98.8	97.6	98.0	94.6	95.5	91.8
0.35	92.9	92.7	91.3	87.6	87.9	86.1
0.40	88.6	89.7	85.9	85.6	84.2	83.1
0.45	86.6	87.5	88.9	85.3	86.4	86.7
0.50	88.7	89.1	86.5	94.2	100.0	86.9
0.55	106.0	102.0	101.0	110.0	106.0	110.0
0.60	106.0	104.0	108.0	104.0	104.0	108.0
0.65	101.0	97.7	110.0	87.9	95.7	106.0
0.70	94.2	86.5	95.8	87.2	98.2	87.4
0.75	97.5	83.4	88.2	85.9	94.3	87.6
0.80	84.6	82.5	86.1	85.2	86.9	84.9
0.85	88.7	86.3	87.1	85.0	92.3	85.5
0.90	94.2	85.9	85.1	82.4	88.7	87.9
0.95	86.0	83.6	85.4	85.0	91.9	88.1
1.00	90.1	86.3	85.1	82.6	91.1	93.3
1.05	89.4	83.5	85.9	85.0	89.8	87.9
1.10	93.1	85.7	83.0	84.2	87.7	88.9
1.15	100.0	89.6	85.2	84.8	97.3	86.4
1.20	94.3	90.1	92.1	90.8	99.8	109.0
1.25	101.0	105.0	109.0	103.0	110.0	109.0
1.30	101.0	110.0	113.0	103.0	103.0	111.0
1.35	108.0	105.0	105.0	90.0	87.3	94.0
1.40	88.1	87.5	84.6	85.5	86.3	88.5
1.45	86.6	85.7	87.1	83.6	85.5	86.2
1.50	87.7	88.9	85.9	88.1	87.5	89.4
1.55	92.5	94.3	92.1	95.1	92.5	97.7
1.60	98.6	99.9	96.5	97.6	101.0	99.7
1.65	109.0	105.0	102.0	103.0	105.0	103.0
1.70	107.0	109.0	106.0	106.0	109.0	104.0
1.75	112.0	111.0	108.0	109.0	110.0	109.0
1.80	114.0	113.0	110.0	115.0	113.0	110.0
1.85	119.0	115.0	112.0	113.0	113.0	112.0
1.90	119.0	117.0	116.0	115.0	116.0	115.0
1.95	119.0	122.0	116.0	117.0	123.0	118.0

Table 5.1

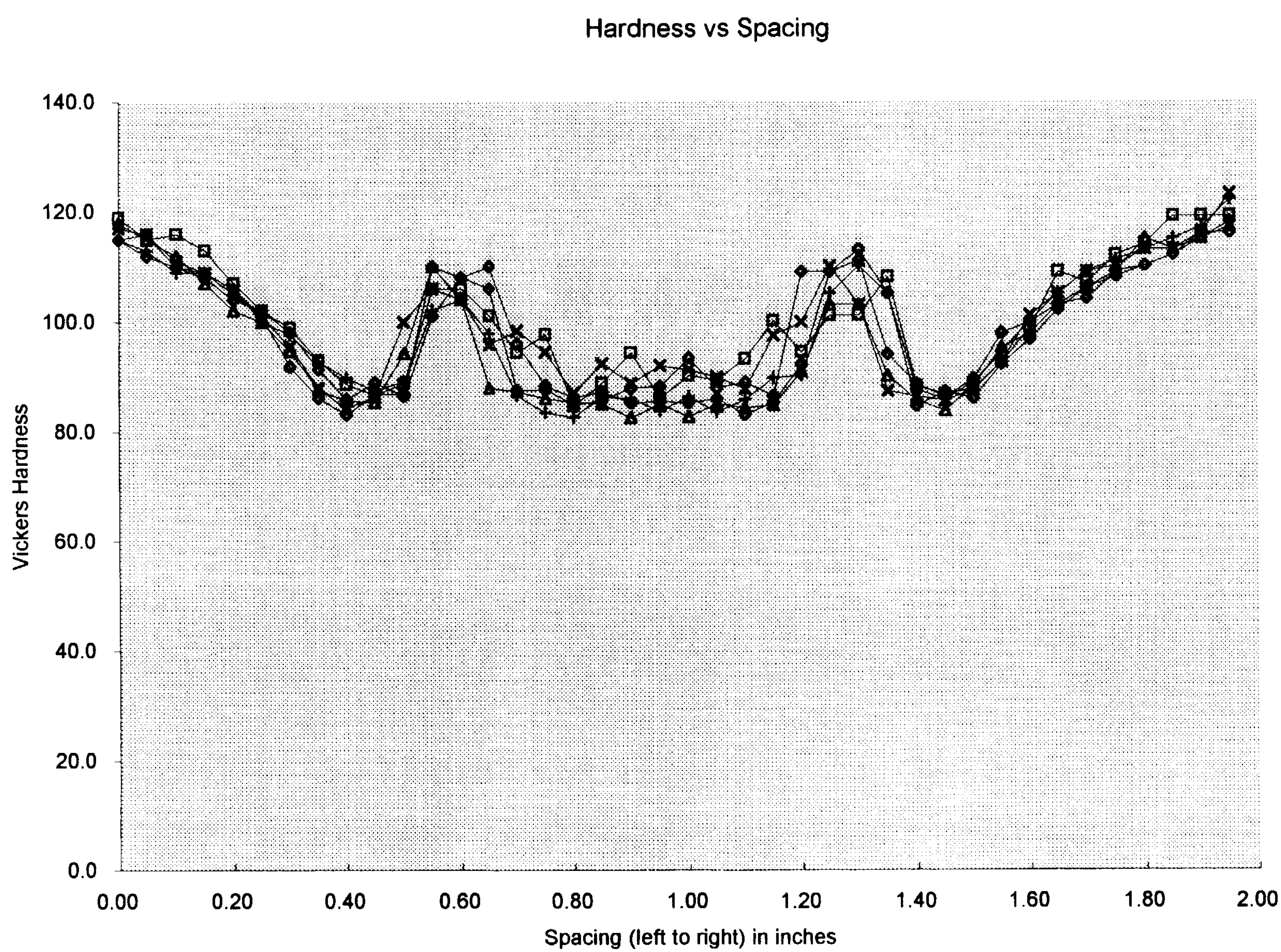

Table 5.1 Graph

6.0 Evaluation / Development Of Theory

Several meetings were held at NASA/MSFC between Dr. Art Nunes (NASA), Jay Lambert (NRC) and Steve Gordon (NRC). Dr. Nunes presented his approach to improve the theory by using a series of 45 degree slip planes throughout a weld of varying hardness, accounting for strain hardening in the weld as strain progresses. This is a considerably more complex theoretical approach than was used in the prior evaluation. Mr. Lambert began work to finish deriving the equations to be used for the theory.

Mr. Lambert reviewed his theory development work with Dr. Nunes who provided guidance for continued development. Mr. Lambert then departed NRC and his work was continued by Mr. Favenesi.

Results bases on the theory development for perfectly aligned parallel-sided welds with no reinforcement were compared to tensile test results for welds that most closely match these conditions. Grid deformations on two tensile test specimens have been evaluated in an attempt to determine how well the theory predicts strain fields within the weld during tensile testing.

Jim Favenesi (NRC) worked on the mathematical development of the geometry effects theory , however he left the company in Sept. '94, so Bob Weed (NRC) replaced him for this task. Strain measurements from the grid on a weld sample were reviewed by Mr. Favenesi and Mr. Weed to determine if they are useful in developing the theory.

The theory was developed for welds with parallel sides and no reinforcement, and for welds with tapered sides and reinforcement. The resulting equations have limited closed form solutions, and appear to require more complex numerical techniques to solve for sharper (i.e. more realistic) transitions of the flow stress function between base metal and weld metal.

Bob Weed's report on "Geometry Effects on Flow and Fracture Stresses in Butt Welds" is included in this report as Appendix 1.

7.0 Weld Geometry Measurement Gauge

A prototype weld geometry measurement gauge was designed and machined. It is intended to be a rugged relatively inexpensive tool to be used in the field to make one sided measurements of both peaking (to nearest degree) and mismatch (to nearest 0.01").

The prototype weld geometry measurement gauge was used to measure the peaking and mismatch of twelve 0.25" thick 2219-T87 aluminum tensile specimens. Mismatch and peaking of these same specimens were then measured from photographs of their cross-sections. Table 7.1 shows the data used to determine gauge accuracy. The average error of gauge measurements, when compared to measurements from cross-sections, was -1.8 degrees peaking and -0.01" mismatch. The standard deviations for these errors were 1.2 degrees for peaking and 0.005" for mismatch. Considering the intent of the gauge this mismatch measuring performance is acceptable, however the errors in the peaking measurements are about twice as much as expected. This is believed to be due primarily to the fit being too loose between the 'peaking plate' and the edge it slides against, resulting in about 1 degree of play. This play could be greatly reduced in future gauges by using tighter tolerances between these mating parts. Some (but probably not much) of the variation may be due to error in measurements made from the weld cross-sections.

Operating instructions and assembly drawings are contained in Appendix II.

Weld Geometry Measurement Guage Accuracy Data

SAMPLE	X-SEC MEASUREMENTS peaking (degrees)	MM (actual) (inches)	GAUGE MEASUREMENTS Peaking (degrees)	Mismatch (inches)	(X-SEC MINUS GAUGE) Peaking (degrees)	Mismatch (inches)
P1818	-0.125	-0.110	0.583	-0.103	-0.708	-0.006
P1819	-1.625	-0.107	0.667	-0.097	-2.292	-0.010
P1820	-0.875	-0.105	0.750	-0.100	-1.625	-0.004
P2106	-2.250	-0.013	1.167	0.005	-3.417	-0.018
P2108	-1.375	-0.005	0.750	0.000	-2.125	-0.005
P2110	-2.625	0.005	0.833	0.008	-3.458	-0.003
P2208	-1.750	-0.122	0.750	-0.107	-2.500	-0.015
P2210	-1.750	-0.114	0.833	-0.107	-2.583	-0.007
P2212	-1.875	-0.120	0.667	-0.107	-2.542	-0.013
T5709	0.125	0.003	0.250	0.010	-0.125	-0.007
T5711	0.500	-0.004	0.250	0.013	0.250	-0.017
T5713	-0.250	-0.006	0.333	0.007	-0.583	-0.012
				HIGHEST:	0.250	0.000
				LOWEST:	-3.458	-0.018
				AVERAGE:	-1.809	-0.010
				STD. DEV.	1.193	0.005

Table 7.1

8.0 Expand Weld Model Database

The data acquisition system and the stand-off sensor (slightly modified to be more heat resistant) were set-up at weld station #6 (Cincinnati-Milicron robot, with Hawks-II controller). Steve Gordon (NRC) was trained on the operation of this system.

A meeting was held on July 19th between NRC, SAIC, and NASA personnel to discuss NRC and SAIC cooperating and sharing data on welds supporting both the Weld Model and SAIC Sensor projects. Cooperation was agreed to, and welding has been completed on an SAIC weld matrix. SAIC will continue to operate their bead profile sensor during the NRC weld matrix to provide weld width measurements. An initial comparison of profiler measurements to hand measurements indicate that the profiler is working fairly well.

A weld matrix test plan was generated for meeting the Option I objectives. Time constants will be measured during welding for step changes in weld current, travel speed, wire feed speed, base metal thickness, and heat sinking.

Welding experiments were performed on weld station #3, using a LVDT-based stand-off sensor to provide ASOC (Automatic Stand-Off Control). With this set-up all the 1/4" thick 2219-T87 aluminum welds were performed. These included welds on plates with pockets machined near the root weld path to locally decrease the heat sink in order to cause weld width variations. These worked well, providing substantial weld width variations. This is only noted for comparison to prior attempts (on other projects) to get similar changes by locally increasing heat sink, which did not result in significant weld width variations. Apparently decreases in heat sink have more affect than increases in heat sink, at least on this material/thickness/parameter combination.

Welding of the 0.250" thick 2219 aluminum, 0.200" thick 2195 aluminum-lithium, and the 0.320" thick 2195 aluminum-lithium were completed. SAIC Bead Profiler weld crown geometry measurements were taken for all welds.

All the welding requirements to support Option I (Weld Model Algorithm Improvements) have been completed.

Data reduction was completed for all the aluminum-lithium (2195) welds, and the data was given to Paul Thompson for analysis to determine how well the previously developed weld model algorithms would have worked for these welds. Four tables show the data accumulated for the 2195 welds. The data for the 0.200" thick plates are contained in tables 8.1 and 8.2. Data for the 0.320" thick plates are contained in tables 8.3 and 8.4.

0.200" 2195: Averages of prior 10 seconds data during a stable portion of the weld

Weld Current Settings: 110 (4") / 130 (4") / 110 (4") / 100 (4") / 110

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current(A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
22-A	18	114.1	99.2	22.8	33.4	22.1	0.0	14.9	13.6	98.1	3.6	3.0
22-B	38	133.8	114.0	23.9	35.3	22.3	0.0	14.6	15.5	104.7	3.6	3.0
22-C	59	114.2	100.9	22.9	33.4	22.3	0.0	14.4	14.1	105.6	3.6	3.0
22-D	79	105.5	97.2	22.7	33.6	22.3	0.0	14.4	13.6	106.3	3.6	3.0
22-E	109	114.3	102.9	23.1	33.7	22.2	0.0	14.5	14.2	106.7	3.6	3.0

Weld Current Settings: 110 (4") / 140 (4") / 110 (2") / 100 (2") / 150 (4") / 110

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
23-A	20	113.9	100.8	22.5	33.3	22.3	0.0	14.8	14.1	101.4	3.6	2.8
23-B	40	144.5	124.0	24.6	36.0	22.4	0.1	14.9	16.3	105.0	3.6	2.8
23-C	52	114.0	103.9	22.7	33.3	22.4	0.0	14.5	14.4	105.9	3.6	2.8
23-D	62	105.9	101.7	22.5	33.0	22.4	0.0	14.5	13.9	106.2	3.6	2.8
23-E	79	154.5	125.9	25.6	37.2	22.4	0.1	15.0	16.8	106.7	3.6	2.8
23-F	109	114.3	106.8	22.9	33.0	22.4	0.0	14.5	14.6	107.1	3.6	2.8

Travel Speed Settings: 12 (4") / 11.5 (4") / 12 (4") / 13 (4") / 12

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
24-A	20	114.0	98.6	22.4	33.6	22.2	0.0	14.7	14.1	103.1	3.6	2.8
24-B	41	114.1	103.2	22.4	33.4	22.3	0.0	14.5	14.3	105.8	3.6	2.8
24-C	60	114.4	104.6	22.5	33.2	22.4	0.0	14.5	14.3	106.5	3.6	2.8
24-D	79	114.6	106.2	22.8	33.4	22.4	0.2	14.5	14.3	106.6	3.6	2.8
24-E	109	114.5	106.0	22.9	33.3	22.3	0.0	14.5	14.4	108.2	3.6	2.8

Table 8.1

0.200'

Weld

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
22-A	12.4	0.267	0.224	0.307	N/A	N/A	Weld OK
22-B	12.1	0.290	0.263	0.328	1.2	1.9	Weld OK
22-C	12.1	0.277	0.224	0.311	1.4	2.0	Weld OK
22-D	12.1	0.263	0.181	0.307	0.9	2.4	Weld OK; SAIC measurement @ 77 secs
22-E	12.0	0.280	0.234	No Data	0.7	2.0	Weld OK

Weld

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
23-A	12.2	0.263	0.216	0.276	N/A	N/A	Weld OK; SAIC based on 3 secs of data
23-B	12.1	0.294	0.273	0.305	0.6	1.2	Weld OK
23-C	12.1	0.269	0.204	0.298	0.7	1.5	Weld OK; NRC measurements based on 9 secs data
23-D	12.1	0.261	0.158	0.329	0.0	1.1	Weld OK; NRC measurements based on 9 secs data
23-E	12.1	0.317	0.312	0.295	1.3	3.0	Started Cutting 1/2 way through; SAIC @ 76 secs
23-F	12.1	0.274	0.199	No Data	2.7	2.9	Quickly stopped cutting

Trave

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
24-A	12.2	0.254	0.199	???	N/A	N/A	Weld OK
24-B	11.6	0.261	0.202	???	0.0	0.0	Weld OK
24-C	12.1	0.267	0.201	???	0.0	0.0	Weld OK
24-D	13.1	0.267	0.186	???	0.0	1.1	Weld OK
24-E	12.1	0.271	0.217	???	0.0	1.1	Weld OK

Table 8.1

Travel Speed Settings: 12 (4") / 10 (4") / 12 (4") / 15 (4") / 12

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
25-A	20	114.3	108.6	22.5	32.4	22.2	0.0	15.4	14.2	103.7	3.6	2.8
25-B	44	114.3	109.1	22.4	32.7	22.3	0.1	14.9	14.6	106.2	3.6	2.8
25-C	64	114.4	108.4	22.6	33.0	22.4	0.0	14.8	14.6	106.9	3.6	2.8
25-D	81	114.6	104.5	23.1	34.1	22.3	0.0	14.8	14.3	107.2	3.6	2.8
25-E	110	114.5	107.4	23.0	33.2	22.4	0.0	14.8	14.7	107.9	3.6	2.8

Plate Thickness Variations: 0" (4") / 0.040" (4") / 0" (4") / 0.032" (4") / 0"

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
26-A	29	331.2	349.0	22.3	31.1	22.4	5.7	14.5	15.3	99.9	2.9	3.0
26-B	59	191.1	200.0	23.4	32.3	22.4	1.9	14.2	14.4	101.2	2.9	3.0
26-C	89	155.3	180.8	23.0	32.2	22.4	3.5	14.1	14.6	101.8	2.9	3.0
26-D	119	460.5	345.8	23.3	32.7	22.4	0.0	14.1	14.7	102.3	2.9	3.0
26-E	148	238.5	189.9	23.6	33.1	22.4	0.0	13.9	14.3	102.6	2.9	3.0

Heat Sink Variations, Pocket Depths: 0" (4") / 0.090" (4") / 0" (4") / 0.055" (4") / 0"

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
27-A	30	114.2	100.0	22.7	33.0	22.0	0.0	14.6	13.5	99.6	2.9	3.0
27-B	60	114.9	96.3	24.2	35.2	22.0	0.0	14.3	13.5	101.1	2.9	3.0
27-C	90	115.1	90.1	23.6	34.3	21.8	0.0	14.1	13.8	102.0	2.9	3.0
27-D	120	116.3	98.0	23.8	34.4	22.2	0.0	13.9	13.8	102.6	2.9	3.0
27-E	149	116.5	98.2	23.8	34.2	22.2	0.0	13.9	13.9	103.0	2.9	3.0

Table 8.1

Trave

	Travel Speed (ipm)	Weld Width (") Crown	Root	SAIC Crown	Transient (Secs) Crown	Root	Comments/ Appearance
25-A	12.2	0.268	0.198	???	N/A	N/A	Weld OK
25-B	10.1	0.278	0.223	???	0.7	1.4	Weld OK
25-C	12.1	0.268	0.201	???	0.6	0.9	Weld OK
25-D	15.1	0.256	0.155	???	0.4	1.5	Weld OK
25-E	12.1	0.269	0.214	???	0.5	2.3	Weld OK

Plate

	Travel Speed (ipm)	Weld Width (") Crown	Root	SAIC Crown	Transient (Secs) Crown	Root	Comments/ Appearance
26-A	9.3	0.303	0.226	No Data	N/A	N/A	Weld Current Measurements Wrong; Weld OK
26-B	9.3	0.300	0.299	No Data	0.0	3.4	Weld Current Measurements Wrong; Weld OK
26-C	9.3	0.309	0.231	No Data	0.0	2.1	Weld Current Measurements Wrong; Weld OK
26-D	9.3	0.315	0.254	No Data	0.0	0.0	Weld Current Measurements Wrong; Weld OK
26-E	9.3	0.314	0.247	No Data	0.0	0.0	Weld Current Measurements Wrong; Weld OK

Heat

	Travel Speed (ipm)	Weld Width (") Crown	Root	SAIC Crown	Transient (Secs) Crown	Root	Comments/ Appearance
27-A	9.1	0.319	0.253	No Data	N/A	N/A	Weld OK
27-B	9.1	0.320	0.350	No Data	0.0	3.7	Weld OK
27-C	9.1	0.323	0.255	No Data	0.0	3.3	Weld OK
27-D	9.1	0.329	0.277	No Data	0.0	1.8	Weld OK
27-E	9.1	0.327	0.256	No Data	0.0	2.2	Weld OK

Table 8.1

0.200" 2195: Averages of prior 10 seconds data during a stable portion of the weld
COVER PASSES

Weld Current Settings: 100 (4") / 110 (4") / 100 (4") / 95 (4") / 100

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
29-A	27	104.8	97.7	21.0	30.5	22.4	0.0	14.2	12.9	106.6	2.2	3.2
29-B	53	113.7	109.2	21.8	30.1	22.3	0.0	14.3	13.7	108.3	2.1	3.2
29-C	78	105.2	105.6	21.8	29.8	22.4	0.0	14.0	13.2	109.0	2.1	3.2
29-D	108	101.3	103.0	21.7	29.6	22.4	0.0	13.9	13.0	109.5	2.1	3.2
29-E	148	105.2	106.0	21.8	29.5	22.4	0.1	14.0	13.4	110.2	2.1	3.2

Weld Current Settings: 105 (4") / 125 (4") / 105 (4") / 90 (4") / 105

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
30-A	26	108.9	103.7	20.9	30.0	23.0	0.0	13.1	13.0	109.9	2.2	3.0
30-B	54	129.6	114.9	22.9	31.4	22.8	0.0	13.7	14.4	111.8	2.2	3.0
30-C	81	109.2	108.8	21.7	29.6	22.9	0.0	13.6	13.7	112.4	2.2	3.0
30-D	108	97.8	97.8	21.2	29.6	23.1	0.0	13.5	12.7	113.0	2.2	3.0
30-E	148	108.9	104.7	22.1	30.4	22.9	0.0	13.6	13.7	114.1	2.2	3.0

Travel Speed Settings: 9 (4") / 8.5 (4") / 9 (4") / 10 (4") / 9

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
31-A	27	105.0	96.9	20.2	30.0	22.6	0.0	13.8	12.6	110.3	2.2	3.0
31-B	55	104.8	98.4	20.3	29.5	22.7	0.0	13.6	12.9	112.1	2.2	3.0
31-C	81	104.8	101.4	20.6	29.4	22.8	0.0	13.6	13.1	113.0	2.2	3.0
31-D	105	105.0	101.1	20.7	29.4	22.8	0.0	13.6	13.2	113.5	2.2	3.0
31-E	146	105.2	104.3	21.1	29.5	22.8	0.0	13.7	13.4	114.1	2.2	3.0

Table 8.2

0.200"

Weld

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
29-A	9.0	0.368	N/A	???	N/A	N/A	Weld OK
29-B	9.0	0.391	N/A	???	2.5	N/A	Weld OK
29-C	9.0	0.389	N/A	???	1.3	N/A	Weld OK
29-D	9.0	0.369	N/A	???	1.1	N/A	Weld OK
29-E	9.0	0.375	N/A	???	0.0	N/A	Weld OK

Weld

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
30-A	9.2	0.362	N/A	???	N/A	N/A	Weld OK
30-B	9.2	0.341	N/A	???	2.5	N/A	One burn-through near end
30-C	9.2	0.371	N/A	???	3.8	N/A	Weld OK
30-D	9.1	0.362	N/A	???	1.8	N/A	Weld OK
30-E	9.1	0.391	N/A	???	2.3	N/A	Weld OK

Travel

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
31-A	9.2	0.367	N/A	???	N/A	N/A	Weld OK
31-B	8.6	0.375	N/A	???	1.7	N/A	Weld OK
31-C	9.1	0.367	N/A	???	1.0	N/A	Weld OK
31-D	10.2	0.350	N/A	???	1.8	N/A	Weld OK
31-E	9.1	0.377	N/A	???	1.6	N/A	Weld OK

Table 8.2

Travel Speed Settings: 9 (4") / 7.5 (4") / 9 (4") / 11 (4") / 9

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
32-A	26	105.0	96.3	20.9	30.7	22.5	0.0	14.1	12.6	111.3	2.2	3.0
32-B	58	104.6	97.9	21.3	30.4	22.6	0.0	13.8	13.2	113.0	2.2	3.0
32-C	85	104.5	98.8	21.6	30.4	22.7	0.0	13.8	13.3	113.7	2.2	3.0
32-D	107	104.7	98.5	21.7	30.6	22.6	0.0	13.9	13.3	114.2	2.2	3.0
32-E	147	104.7	98.8	22.2	30.8	22.6	0.0	13.9	13.3	114.6	2.2	3.0

Wire Feed Speed Settings: 20 (4") / 10 (4") / 20 (4") / 25 (4") / 20 : Using 0.063" dia 2319 wire

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
33-A	26	104.9	97.9	21.0	30.3	22.6	0.0	14.0	12.8	111.5	2.2	3.0
33-B	53	105.0	96.9	21.4	31.0	22.7	0.0	13.9	12.9	113.2	2.2	3.0
33-C	78	104.7	99.9	21.3	30.0	22.7	0.0	13.8	13.3	114.1	2.2	3.0
33-D	105	104.8	101.2	21.5	29.9	22.7	0.0	13.8	13.4	114.5	2.2	3.0
33-E	146	104.7	99.8	21.7	30.1	22.7	0.0	13.8	13.4	114.9	2.2	3.0

Table 8.2

Travel

	Travel Speed (ipm)	Weld Width (") Crown	Root	SAIC Crown	Transient (Secs) Crown	Root	Comments/ Appearance
32-A	9.2	0.376	N/A	???	N/A	N/A	Weld OK
32-B	7.6	0.401	N/A	???	4.5	N/A	Weld OK
32-C	9.2	0.377	N/A	???	4.9	N/A	Weld OK
32-D	11.2	0.343	N/A	???	2.8	N/A	Weld OK
32-E	9.1	0.361	N/A	???	2.4	N/A	Weld OK

Wire F

	Travel Speed (ipm)	Weld Width (") Crown	Root	SAIC Crown	Transient (Secs) Crown	Root	Comments/ Appearance
33-A	9.0	0.359	N/A	???	N/A	N/A	Weld OK
33-B	9.0	0.359	N/A	???	0.0	N/A	Weld OK
33-C	9.0	0.365	N/A	???	1.9	N/A	Weld OK
33-D	9.0	0.375	N/A	???	2.3	N/A	Weld OK
33-E	9.0	0.378	N/A	???	0.9	N/A	Weld OK

Table 8.2

0.320" 2195: Averages of prior 10 seconds data during a stable portion of the weld
ROOT PASSES

Weld Current Settings: 160 (4") / 165 (4") / 160 (4") / 150 (4") / 160

	Time	Weld Current(A)		Weld Voltage(V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
42-A	21	165.1	134.6	27.4	39.0	22.2	0.0	15.9	18.7	103.6	4.3	3.0	11.2
42-B	44	170.6	140.5	27.4	38.5	22.4	0.0	15.5	19.2	104.3	4.4	3.0	11.1
42-C	66	165.2	138.8	27.0	38.4	22.5	0.0	15.2	19.1	104.8	4.4	3.0	11.1
42-D	86	154.6	134.0	26.3	37.8	22.6	0.0	14.9	18.8	105.2	4.4	3.0	11.1
42-E	114	165.2	138.9	27.1	38.6	22.6	0.0	15.0	19.2	105.6	4.4	3.0	11.1

Weld Current Settings: 160 (4") / 175 (4") / 160 (4") / 140 (4") / 160

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
43-A	22	164.9	137.1	27.2	38.0	22.3	0.0	15.8	18.9	100.4	4.3	3.0	11.2
43-B	44	180.7	147.0	28.5	39.4	22.4	0.0	15.6	19.8	104.2	4.4	3.0	11.1
43-C	66	165.2	138.9	27.1	38.1	22.6	0.0	15.1	19.4	105.0	4.4	3.0	11.1
43-D	88	143.7	107.7	26.0	39.9	21.8	0.0	14.7	17.9	105.6	4.4	3.0	11.1
43-E	115	165.1	138.1	27.2	38.6	22.6	0.0	15.0	19.4	106.0	4.4	3.0	11.1

Travel Speed Settings: 11 (4") / 10 (4") / 11 (4") / 11.5 (4") / 11

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
44-A	23	165.4	135.1	26.4	36.8	22.5	0.0	15.3	19.3	107.2	4.3	3.0	11.3
44-B	46	165.1	138.6	26.8	36.9	22.5	0.0	15.4	19.5	108.9	4.4	3.0	10.2
44-C	67	165.9	140.7	26.8	36.6	22.6	0.0	15.4	19.8	109.2	4.4	3.0	11.2
44-D	87	165.4	139.5	27.3	37.4	22.6	0.0	15.3	19.6	109.2	4.4	3.0	11.7
44-E	115	165.6	139.8	27.2	37.3	22.6	0.0	15.2	19.8	109.4	4.4	3.0	11.2

Table 8.3

0.320'

Weld

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
42-A	0.300	0.216	***	N/A	N/A	Donut stuck; Weld OK when released
42-B	0.309	0.243	***	0.0	1.7	Weld OK
42-C	0.314	0.232	***	0.0	0.0	Weld OK
42-D	0.304	0.211	***	0.0	1.3	Weld OK
42-E	0.316	0.230	***	1.1	3.3	Weld OK

Weld

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
43-A	0.296	0.226	***	N/A	N/A	Weld OK
43-B	0.326	0.271	***	1.2	1.2	Weld OK
43-C	0.312	0.219	***	1.8	3.2	Weld OK
43-D	0.297	0.179	***	1.7	1.4	Weld OK; Best Appearance Of All
43-E	0.315	0.245	***	1.9	4.7	Weld OK

Trave

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
44-A	0.315	0.215	***	N/A	N/A	Weld OK
44-B	0.313	0.226	***	0.0	0.0	Weld OK
44-C	0.310	0.231	***	1.1	0.0	Weld OK
44-D	0.315	0.236	***	0.0	0.0	Weld OK
44-E	0.317	0.231	***	0.0	1.1	Weld OK

Table 8.3

Travel Speed Settings: 11 (4") / 9 (4") / 11 (4") / 12.5 (4") / 11

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
45-A	22	165.4	137.8	27.1	37.9	22.3	0.0	15.8	18.8	105.3	4.4	3.0	11.2
45-B	48	165.2	139.5	27.3	37.6	22.5	0.0	15.4	19.5	107.9	4.4	3.0	9.1
45-C	70	165.4	141.2	27.1	37.2	22.6	0.0	15.3	19.9	108.5	4.4	3.0	11.1
45-D	89	165.5	137.8	27.7	39.0	22.5	0.0	15.3	19.7	109.0	4.4	3.0	12.7
45-E	117	165.3	142.4	27.1	37.4	22.6	0.0	15.2	20.1	109.4	4.4	3.0	11.1

Plate Thickness Variations: 0 (4") / 0.110 (4") / 0 (4") / 0.055 (4") / 0

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
46-A	22	164.9	133.5	27.8	38.8	22.2	0.0	15.4	18.8	103.9	4.4	3.0	11.2
46-B	43	165.8	135.3	27.9	40.2	22.3	0.0	15.2	19.1	107.8	4.4	3.0	11.1
46-C	64	165.4	141.0	27.4	37.8	22.4	0.0	15.1	19.7	108.5	4.4	3.0	11.1
46-D	85	165.6	141.2	27.3	38.0	22.5	0.0	15.0	19.7	109.1	4.4	3.0	11.1
46-E	115	165.4	141.1	27.4	37.5	22.5	0.0	14.8	19.7	109.6	4.4	3.0	11.1

Heat Sink Variations, Pocket Depths: 0 (4") / 0.120 (4") / 0 (4") / 0.050 (4") / 0

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
47-A	22	164.7	137.0	27.9	37.8	22.3	0.0	15.0	17.1	106.3	4.4	3.0	11.2
47-B	34	165.6	139.8	28.2	39.4	22.4	0.0	15.3	19.3	107.9	4.4	3.0	11.1
47-C	64	165.5	140.4	27.8	38.5	22.4	0.0	15.1	19.6	109.3	4.4	3.0	11.1
47-D	85	165.7	140.8	28.1	39.0	22.5	0.0	15.0	19.6	109.7	4.4	3.0	11.1
47-E	115	165.4	140.3	27.7	38.5	22.6	0.0	14.9	19.8	110.1	4.4	2.9	11.1

Table 8.3

Trave

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
45-A	0.306	0.221	***	N/A	N/A	Weld OK
45-B	0.336	0.247	***	4.1	1.2	Weld OK
45-C	0.322	0.221	***	2.9	3.2	Weld OK
45-D	0.315	0.259	***	0.0	4.8	Excessive Drop-Through
45-E	0.314	0.222	***	1.3	2.7	Weld OK

Plate

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
46-A	0.325	0.245	***	N/A	N/A	Weld OK
46-B	0.330	0.267	***	2.0	2.8	Weld OK
46-C	0.317	0.229	***	1.3	1.5	Weld OK
46-D	0.321	0.237	***	0.0	1.8	Weld OK
46-E	0.329	0.236	***	0.0	1.8	Weld OK

Heat !

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
47-A	0.328	0.251	***	N/A	N/A	Weld OK
47-B	0.314	0.377	***	1.0	6.9	Weld OK half way, then over-pen, int. cutting
47-C	0.323	0.238	***	1.6	5.5	Weld OK
47-D	0.324	0.283	***	0.0	1.3	Weld OK
47-E	0.326	0.241	***	1.3	0.9	Weld OK

Table 8.3

0.320" 2195: Averages of prior 10 seconds data during a stable portion of the weld
COVER PASSES

Weld Current Settings: 155 (4") / 165 (4") / 155 (4") / 150 (4") / 155

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
49-A	36	160.0	139.0	24.4	33.2	22.9	0.0	13.9	16.6	111.1	1.5	3.6
49-B	71	170.0	147.9	25.1	32.5	22.8	0.0	14.0	15.8	112.4	1.5	3.6
49-C	104	159.9	142.3	24.6	33.2	22.9	0.0	14.0	17.2	113.1	1.5	3.6
49-D	140	154.5	138.0	24.4	33.0	22.9	0.0	13.8	16.7	113.7	1.5	3.6
49-E	183	159.8	136.5	24.7	33.7	22.9	0.0	14.0	17.1	114.1	1.5	3.5

Weld Current Settings: 155 (4") / 170 (4") / 155 (4") / 145 (4") / 155

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
50-A	37	159.7	138.4	24.2	32.9	22.8	0.0	14.0	16.2	112.5	1.5	3.6
50-B	70	175.5	150.2	25.2	33.4	22.8	0.0	14.2	17.5	114.0	1.5	3.6
50-C	105	159.7	136.1	24.5	33.6	22.9	0.0	13.9	17.0	114.6	1.5	3.6
50-D	141	149.1	128.5	24.0	33.6	22.9	0.0	13.7	16.5	115.1	1.5	3.6
50-E	184	159.5	135.0	24.2	33.5	22.9	0.0	13.9	16.9	115.5	1.5	3.4

Travel Speed Settings: 7 (4") / 8 (4") / 7 (4") / 6.5 (4") / 7

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
51-A	34	158.0	142.6	23.2	31.4	22.8	0.0	13.7	17.2	113.5	1.6	3.6
51-B	60	158.0	142.1	23.6	31.8	23.0	0.0	13.3	17.9	114.4	1.5	3.6
51-C	98	158.2	140.7	23.8	32.6	23.0	0.0	13.1	17.7	115.1	1.5	3.5
51-D	136	157.9	137.7	23.9	33.2	23.0	0.0	13.0	17.4	115.6	1.5	3.6
51-E	179	157.5	127.9	24.0	33.7	22.6	0.0	13.0	17.3	115.8	1.5	3.5

Table 8.4

0.320'

Weld

	Travel Speed (ipm)	Weld Width (") Crown	Weld Width (") Root	SAIC Crown	Transient (Secs) Crown	Transient (Secs) Root	Comments/ Appearance
49-A	7.1	0.509	N/A	***	N/A	N/A	Weld OK
49-B	7.1	0.480	N/A	***	6.2	N/A	Weld OK
49-C	7.1	0.502	N/A	***	13.1	N/A	Weld OK
49-D	7.1	0.506	N/A	***	1.5	N/A	Weld OK
49-E	7.1	0.506	N/A	***	0.0	N/A	Weld OK

Weld

	Travel Speed (ipm)	Weld Width (") Crown	Weld Width (") Root	SAIC Crown	Transient (Secs) Crown	Transient (Secs) Root	Comments/ Appearance
50-A	7.1	0.513	N/A	***	N/A	N/A	Weld OK
50-B	7.1	0.483	N/A	***	8.3	N/A	Weld OK
50-C	7.1	0.521	N/A	***	10.5	N/A	Weld OK
50-D	7.1	0.498	N/A	***	3.9	N/A	Weld OK
50-E	7.1	0.516	N/A	***	6.3	N/A	Weld OK

Trave

	Travel Speed (ipm)	Weld Width (") Crown	Weld Width (") Root	SAIC Crown	Transient (Secs) Crown	Transient (Secs) Root	Comments/ Appearance
51-A	7.1	0.454	N/A	***	N/A	N/A	Weld OK
51-B	8.1	0.452	N/A	***	1.4	N/A	Weld OK
51-C	7.1	0.492	N/A	***	3.4	N/A	Weld OK
51-D	6.6	0.521	N/A	***	8.0	N/A	Weld OK
51-E	7.1	0.509	N/A	***	2.0	N/A	Weld OK

Table 8.4

Travel Speed Settings: 7 (3") / 9 (3") / 7 (4") / 5.5 (4") / 7

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
52-A	29	158.2	141.1	24.8	32.8	22.5	0.0	13.8	17.8	115.0	1.6	3.8
52-B	49	158.1	142.1	25.1	33.1	22.5	0.0	14.0	18.8	115.2	1.5	3.8
52-C	83	158.2	141.3	25.2	33.1	22.4	0.0	13.9	18.7	115.6	1.5	3.8
52-D	126	158.0	140.3	25.3	33.6	22.4	0.0	14.0	18.6	115.9	1.5	3.8
52-E	187	157.4	141.9	25.2	31.5	22.6	0.0	12.9	16.6	116.2	1.5	3.7

Wire Feed Speed Settings: 40 (6") / 50 (2") / 40 (2") / 20 (5.75") / 40

at 7ipm, 2" takes			17.1	secs	51.4	68.6	85.7	135.0	150.1			
	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
53-A	49	157.9	142.1	24.6	32.8	22.6	0.0	13.3	17.9	115.0	1.5	3.7
53-B	66	157.8	142.1	24.7	32.7	22.6	0.0	13.5	18.1	115.2	1.5	3.7
53-C	83	157.6	142.6	24.8	32.1	22.6	0.0	13.4	17.2	115.5	1.5	3.7
53-D	132	157.3	130.9	26.6	34.3	22.3	0.0	12.9	16.0	115.9	1.5	3.7
53-E	148	157.7	140.8	25.2	33.2	22.6	0.0	13.6	18.1	116.0	1.5	3.7

Table 8.4

Trave

	Travel Speed (ipm)	Weld Width (") Crown	Root	SAIC Crown	Transient (Secs) Crown	Root	Comments/ Appearance
52-A	7.2	0.461	N/A	***	N/A	N/A	Weld OK
52-B	9.2	0.434	N/A	***	3.6	N/A	Weld OK
52-C	7.2	0.487	N/A	***	2.9	N/A	Weld OK
52-D	5.7	0.516	N/A	***	3.2	N/A	Weld OK
52-E	7.2	0.458	N/A	***	2.7	N/A	Weld OK

Wire I
at 7ipı

	Travel Speed (ipm)	Weld Width (") Crown	Root	SAIC Crown	Transient (Secs) Crown	Root	Comments/ Appearance
53-A	7.1	0.439	N/A	***	N/A	N/A	Weld OK
53-B	7.1	0.445	N/A	***	0.0	N/A	Weld OK
53-C	7.1	0.446	N/A	***	3.9	N/A	Weld OK
53-D	7.1	0.470	N/A	***	2.0	N/A	Excess pen to 4.5" (root probs), last 1.5" OK
53-E	7.1	0.440	N/A	***	2.2	N/A	Weld OK

Table 8.4

It has proven difficult to interpret the SAIC weld width data. Weld widths are being measured by hand with calipers, and these measurements were compared to SAIC data to aid in its interpretation.

Data reduction was completed for all the 2219 aluminum welds, and the data was delivered to Paul Thompson for analysis to determine how well the previously developed weld model algorithms would have worked for these welds. This completes all the data reduction requirements for this task. Data for the 2219 1/4" aluminum welds are contained in table 8.5 and 8.6.

0.250" 2219: Averages of prior 10 seconds data during a stable portion of the weld
ROOT PASSES

Weld Current Settings: 125 (4") / 135 (4") / 125 (4") / 105 (4") / 125

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
02A-A	34	129.4	114.7	29.1	39.8	21.8	0.0	16.4	14.9	92.4	7.1	3.6
02A-B	64	139.7	120.8	29.7	40.7	22.0	0.0	16.1	15.6	93.7	7.1	3.6
02A-C	94	129.2	114.3	29.1	40.0	21.9	0.0	16.2	14.9	94.4	7.1	3.6
02A-D	124	109.8	92.4	28.4	40.0	21.4	0.0	16.5	12.5	94.8	7.1	3.6
02A-E	167	129.3	113.1	29.2	40.1	21.8	0.0	16.2	15.1	95.4	7.1	3.6

Weld Current Settings: 110 (4") / 140 (4") / 100 (4") / 140 (4") / 110

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
03A-A	32	115.3	95.1	28.7	40.5	21.5	0.0	16.7	12.9	92.9	7.2	3.5
03A-B	62	144.7	126.2	29.4	40.4	22.0	0.0	16.2	16.4	93.6	7.1	3.5
03A-C	92	105.8	93.4	28.2	39.2	21.6	0.0	16.4	12.4	94.7	7.2	3.5
03A-D	122	144.7	122.6	29.7	40.5	21.8	0.0	16.1	16.3	95.1	7.1	3.5
03A-E	170	114.1	98.9	28.5	40.2	21.6	0.0	16.3	13.5	95.7	7.1	3.5

Travel Speed Settings: 8 (4") / 8.5 (4") / 8 (4") / 7 (4") / 8

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
04A-A	27	129.9	106.9	29.4	41.3	21.6	0.0	16.8	14.4	94.1	7.1	3.4
04A-B	62	129.8	101.5	29.5	41.4	21.4	0.0	16.4	14.3	95.2	7.2	3.5
04A-C	91	129.9	108.9	29.4	41.2	21.9	0.0	16.4	14.5	95.7	7.2	3.5
04A-D	123	129.8	108.8	29.4	41.2	21.9	0.0	16.4	14.6	96.2	7.2	3.5
04A-E	177	125.0	110.9	27.8	39.0	22.1	0.0	15.8	14.6	96.8	6.8	3.4

Table 8.5

0.250"

Weld (

	Travel Speed (ipm)	Weld Width (") Crown	Weld Width (") Root	SAIC Crown	Transient (Secs) Crown	Transient (Secs) Root	Comments/ Appearance
02A-A	8.1	0.322	0.241	***	N/A	N/A	Weld OK
02A-B	8.1	0.346	0.259	***	2.2	3.4	Weld OK
02A-C	8.1	0.329	0.241	***	2.3	2.9	Weld OK
02A-D	8.1	0.308	0.191	***	1.9	1.9	Weld OK
02A-E	8.1	0.339	0.239	***	3.0	3.3	Weld OK

Weld (

	Travel Speed (ipm)	Weld Width (") Crown	Weld Width (") Root	SAIC Crown	Transient (Secs) Crown	Transient (Secs) Root	Comments/ Appearance
03A-A	8.2	0.301	0.192	***	N/A	N/A	Slight Suckback
03A-B	8.2	0.352	0.247	***	3.7	3.5	Weld OK
03A-C	8.2	0.303	0.182	***	1.8	3.0	Slight Suckback
03A-D	8.2	0.358	0.242	***	3.4	4.1	Weld OK
03A-E	8.1	0.311	0.203	***	2.1	3.6	Slight Suckback

Travel

	Travel Speed (ipm)	Weld Width (") Crown	Weld Width (") Root	SAIC Crown	Transient (Secs) Crown	Transient (Secs) Root	Comments/ Appearance
04A-A	8.9	0.326	0.228	***	N/A	N/A	Weld OK
04A-B	9.0	0.333	0.226	***	0.0	0.0	Weld OK
04A-C	8.2	0.334	0.230	***	0.0	0.0	Weld OK
04A-D	7.2	0.347	0.245	***	1.2	0.0	Weld OK
04A-E	8.7	0.342	0.237	***	2.1	2.1	Weld OK

Table 8.5

Travel Speed Settings: 8 (4") / 6.5 (4") / 8 (4") / 10 (4") / 8

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
05A-A	33	129.7	112.4	29.0	40.5	21.9	0.0	16.6	15.0	94.6	7.2	3.5
05A-B	64	129.9	109.8	29.1	40.8	21.8	0.0	16.5	14.8	95.7	7.2	3.5
05A-C	99	130.0	106.1	29.1	41.3	21.7	0.0	16.4	14.6	96.4	7.2	3.4
05A-D	124	129.7	106.2	29.3	41.4	21.7	0.1	16.4	14.5	96.8	7.2	3.5
05A-E	174	127.7	106.7	28.4	40.4	21.8	0.0	16.0	14.4	97.3	7.0	3.4

Plate Thickness Variations: 0" (4") / 0.090" (4") / 0" (4") / 0.050" (4") / 0"

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
06A-A	30	114.7	94.1	28.2	39.2	21.8	0.0	16.7	13.9	90.4	7.1	3.4
06A-B	57	114.3	100.6	26.9	38.0	22.0	0.0	16.5	14.6	91.7	7.1	3.4
06A-C	85	114.6	94.1	27.8	39.0	21.9	0.0	16.5	14.2	92.1	7.1	3.4
06A-D	113	114.9	93.1	27.5	39.2	22.0	0.0	16.4	14.0	92.5	7.1	3.4
06A-E	164	114.3	96.1	27.8	38.9	22.0	0.0	16.3	14.3	92.8	7.1	3.4

Heat Sink Variations, Pocket Depths: 0" (4") / 0.160" (4") / 0" (4") / 0.090" (4") / 0"

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)
07A-A	26	109.8	89.9	29.3	41.2	21.7	0.0	17.0	12.6	90.5	7.1	3.4
07A-B	49	108.7	92.8	27.4	39.3	22.0	0.0	16.5	13.4	91.8	7.1	3.4
07A-C	72	110.3	90.8	29.4	41.4	21.9	0.0	16.3	13.0	92.4	7.1	3.4
07A-D	96	110.4	90.9	28.8	41.3	22.0	0.0	16.2	13.0	92.6	7.1	3.4
07A-E	135	109.9	92.4	29.2	41.4	22.0	0.0	16.1	13.1	93.0	7.1	3.4

Table 8.5

Travel

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
05A-A	8.1	0.326	0.231	***	N/A	N/A	Slight Suckback
05A-B	6.6	0.353	0.248	***	1.5	0.0	Weld OK
05A-C	8.1	0.331	0.222	***	3.1	0.0	Slight Suckback
05A-D	10.1	0.320	0.214	***	1.8	0.0	Weld OK
05A-E	8.1	0.339	0.218	***	1.6	0.0	Slight Suckback

Plate T

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
06A-A	8.3	0.320	0.180	***	N/A	N/A	Severe Suckback
06A-B	8.3	0.299	0.179	***	2.4	1.2	Weld OK
06A-C	8.3	0.301	0.183	***	2.4	1.4	Severe Suckback
06A-D	8.3	0.309	0.208	***	1.8	1.0	Weld OK
06A-E	8.3	0.326	0.182	***	2.2	2.0	Severe Suckback

Heat S

	Travel Speed (ipm)	Weld Width (")		SAIC Crown	Transient (Secs)		Comments/ Appearance
		Crown	Root		Crown	Root	
07A-A	10.2	0.295	0.190	***	N/A	N/A	Weld OK
07A-B	10.1	0.317	0.473	***	4.2	5.2	Intermittent Cutting
07A-C	10.1	0.310	0.186	***	4.7	3.7	Weld OK
07A-D	10.1	0.315	0.313	***	1.0	4.8	Weld OK
07A-E	10.1	0.301	0.186	***	2.6	3.1	Weld OK

Table 8.5

0.250" 2219: Averages of prior 10 seconds data during a stable portion of the weld
COVER PASSES (0.063" DIA. 2319 WIRE FED AT 30 IPM UNLESS OTHERWISE NOTED)

Weld Current Settings: 100 (4") / 110 (4") / 100 (4") / 95 (4") / 100

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
09-A	38	105.1	103.0	23.8	32.7	22.3	0.0	15.0	12.1	91.6	2.1	4.7	7.7
09-B	70	114.5	108.6	24.7	33.3	22.4	0.0	14.8	13.0	92.6	2.1	4.7	7.7
09-C	103	105.3	102.0	24.4	33.0	22.5	0.0	14.6	12.7	93.2	2.0	4.7	7.9
09-D	135	101.3	100.7	23.9	33.0	22.5	0.0	14.6	12.6	93.7	2.0	4.7	7.9
09-E	178	105.2	102.9	24.1	33.1	22.5	0.0	14.6	12.8	93.9	2.0	4.7	7.9

Weld Current Settings: 105 (4") / 125 (4") / 105 (4") / 90 (4") / 105

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
10-A	34	109.5	102.0	24.1	34.4	22.8	0.0	14.2	12.3	82.1	2.1	4.8	7.6
10-B	69	129.1	121.0	25.8	35.2	22.8	0.0	14.4	14.0	83.0	2.0	4.8	7.6
10-C	101	109.1	104.0	24.4	33.7	22.8	0.0	14.3	12.9	83.5	2.0	4.8	7.6
10-D	133	97.3	97.0	23.9	33.3	22.8	0.0	14.4	12.4	83.8	2.0	4.8	7.6
10-E	174	109.0	103.4	24.9	34.2	22.7	0.0	14.3	13.0	84.2	2.0	4.8	7.6

Travel Speed Settings: 7.5 (4") / 7 (4") / 7.5 (4") / 8.5 (4") / 7.5

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
11-A	38	105.4	101.7	24.0	34.1	22.8	0.0	14.2	12.4	83.8	2.1	4.8	7.6
11-B	73	105.2	102.2	24.3	34.0	22.8	0.1	14.3	12.6	84.9	2.0	4.8	7.0
11-C	105	105.2	101.8	24.5	34.0	22.8	0.0	14.4	12.7	85.2	2.0	4.8	7.6
11-D	133	105.2	102.4	24.6	34.0	22.8	0.0	14.5	12.8	85.4	2.0	4.8	8.6
11-E	160	105.2	102.0	24.7	34.0	22.7	0.0	14.5	12.8	85.6	2.0	4.8	7.6

Table 8.6

0.250

Weld

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
09-A	0.381	N/A	***	N/A	N/A	Weld OK
09-B	0.419	N/A	***	2.7	N/A	Weld OK
09-C	0.379	N/A	***	3.0	N/A	Weld OK
09-D	0.360	N/A	***	0.0	N/A	Weld OK
09-E	0.374	N/A	***	2.0	N/A	Weld OK

Weld

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
10-A	0.411	N/A	***	N/A	N/A	Weld OK
10-B	0.480	N/A	***	3.4	N/A	Weld OK
10-C	0.421	N/A	***	5.5	N/A	Weld OK
10-D	0.357	N/A	***	4.7	N/A	Weld OK
10-E	0.397	N/A	***	2.5	N/A	Weld OK

Trave

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
11-A	0.389	N/A	***	N/A	N/A	Weld OK
11-B	0.397	N/A	***	0.0	N/A	Weld OK
11-C	0.391	N/A	***	1.6	N/A	Weld OK
11-D	0.362	N/A	***	2.2	N/A	Weld OK
11-E	0.385	N/A	***	1.5	N/A	Weld OK

Table 8.6

Travel Speed Settings: 7.5 (4") / 6 (4") / 7.5 (4") / 9.5 (4") / 7.5

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
12-A	35	105.1	103.9	23.1	31.9	22.5	0.0	14.0	12.4	85.7	2.1	5.1	7.7
12-B	78	105.1	104.5	23.7	31.7	22.4	0.0	14.1	12.7	87.0	2.1	5.1	6.1
12-C	110	105.2	103.8	23.8	32.1	22.5	0.0	14.1	12.6	87.5	2.1	5.1	7.6
12-D	134	105.2	103.6	23.9	32.5	22.5	0.0	14.1	12.7	87.8	2.1	5.1	9.7
12-E	181	105.2	102.9	24.3	32.8	22.5	0.0	14.1	12.7	88.1	2.0	5.1	7.6

Wire Feed Speed Settings: 30 (4") / 35 (4") / 30 (4") / 20 (4") / 30: Using 0.063" dia 2319 wire

	Time	Weld Current (A)		Weld Voltage (V)		Pilot Current (A)		Pilot Voltage (V)		SGas	PGas	Stand-Off	Travel Speed
	(secs)	Forward	Reverse	Forward	Reverse	Forward	Reverse	Forward	Reverse	(scfh)	(scfh)	(mm)	(ipm)
13-A	35	105.8	103.6	22.8	32.6	22.5	0.0	14.0	12.2	88.6	2.1	4.9	7.6
13-B	67	105.8	104.0	23.0	32.2	22.6	0.0	14.1	12.5	89.7	2.1	4.9	7.6
13-C	98	105.8	104.0	23.3	32.4	22.6	0.0	14.1	12.7	90.3	2.1	4.9	7.6
13-D	130	105.8	103.3	23.8	32.8	22.5	0.0	14.2	12.6	90.6	2.1	4.9	7.6
13-E	171	105.8	103.6	23.7	32.6	22.6	0.0	14.3	12.9	91.0	2.1	4.9	7.6

Table 8.6

Trave

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
12-A	0.375	N/A	***	N/A	N/A	Weld OK
12-B	0.378	N/A	***	1.9	N/A	Weld OK
12-C	0.374	N/A	***	4.0	N/A	Weld OK
12-D	0.323	N/A	***	4.2	N/A	Weld OK
12-E	0.356	N/A	***	1.8	N/A	Weld OK

Wire I

	Weld Width (")			Transient (Secs)		Comments/
	Crown	Root	SAIC Crown	Crown	Root	Appearance
13-A	0.365	N/A	***	N/A	N/A	Weld OK
13-B	0.367	N/A	***	0.0	N/A	Weld OK
13-C	0.357	N/A	***	0.0	N/A	Weld OK
13-D	0.378	N/A	***	2.4	N/A	Weld OK
13-E	0.370	N/A	***	1.7	N/A	Weld OK

Table 8.6

At the request of Dr. Nunes, the NASA COTAR for this project, additional weld data was provided. This data consisted of depth-to-width ratios for 2195 aluminum-lithium welds made at varying torch stand-offs and shield gas flow rates (measurements from 29 cross-sections were provided) and a 2219 aluminum weld made at varying shield gas flow rates (measurements from 21 cross-sections were provided). This data was compared to predictions from a hypotheses regarding the change in depth-to-width ratio as a function of differential contamination of the shield gas coverage. This differential contamination of the shield gas coverage is expected to vary with changes in both stand-off and shield gas flow rates. Observed trends in the data were not as expected based upon the hypothesis. The data obtained, and the hypothesis, are being reviewed further. The data and a graph for the 2195 aluminum-lithium are contained in table 8.7. Data and a graph from the 2219 aluminum are contained in table 8.8.

partial penetration bead-on-plate welds

Weld Inch	Plate Number	Stand-Off (mm)	Arc Current Forward (A)	Arc Current Reverse (A)	Arc Voltage Forward (V)	Arc Voltage Reverse (V)	SGas (scfh He)	PGas (scfh Ar)	Travel Speed (ipm)	Weld Depth (")	Weld Width (")	Weld D/W Ratio
4	SOVV6	1.1	149.7	138.3	21.1	29.0	84.4	1.6	7.1	0.145	0.276	0.525
19	SOVV6	1.2	149.4	140.3	21.8	28.2	86.3	1.5	7.1	0.180	0.362	0.497
5	SOVV6	1.3	150.0	138.3	21.1	28.9	84.4	1.5	7.1	0.137	0.295	0.464
3	SOVV6	2.0	149.7	129.9	22.0	29.8	83.7	1.6	7.1	0.142	0.310	0.458
6	SOVV6	2.2	148.3	135.8	22.1	30.4	85.0	1.5	7.1	0.140	0.310	0.452
18	SOVV6	2.3	148.8	128.7	22.8	31.1	85.9	1.5	7.1	0.156	0.335	0.466
14	SOVV6	2.5	149.0	129.5	23.0	31.4	85.5	1.5	7.1	0.174	0.348	0.500
7	SOVV6	2.8	148.7	134.3	22.6	31.2	85.0	1.5	7.1	0.142	0.335	0.424
1	SOVV6	3.0	148.8	133.6	23.0	30.9	79.9	1.7	7.9	0.132	0.340	0.388
13	SOVV6	3.3	148.7	110.1	24.7	35.7	85.7	1.5	7.1	0.200	0.387	0.517
16	SOVV6	3.3	148.5	122.9	24.1	33.4	86.0	1.5	7.1	0.185	0.389	0.476
17	SOVV6	3.4	148.6	123.8	23.9	32.9	85.9	1.5	7.1	0.157	0.294	0.534
2	SOVV6	3.6	148.9	123.6	24.1	32.6	83.0	1.6	7.1	0.170	0.379	0.449
15	SOVV6	3.7	148.9	117.9	24.4	34.0	85.9	1.5	7.1	0.193	0.430	0.449
8	SOVV6	3.8	148.2	115.8	24.6	34.5	85.5	1.5	7.1	0.168	0.395	0.425
12	SOVV6	4.2	147.9	113.5	26.7	34.7	85.7	1.5	7.1	0.219	0.413	0.530
9	SOVV6	4.4	148.6	110.8	25.7	35.5	85.3	1.5	7.1	0.217	0.454	0.478
10	SOVV6	4.9	148.4	101.6	26.8	37.1	85.8	1.5	7.1	0.246	0.471	0.522
11	SOVV6	5.5	148.5	104.1	27.8	38.7	85.7	1.5	7.1	0.263	0.472	0.557
18	SOVV7	0.8	148.6	140.3	16.4	21.0	47.1	1.5	7.1	0.157	0.280	0.561
17	SOVV7	1.1	149.0	121.2	21.5	30.1	47.0	1.5	7.1	0.157	0.289	0.543
5	SOVV7	1.2	149.7	134.6	21.2	29.9	46.8	1.6	7.1	0.149	0.285	0.523
4	SOVV7	1.3	149.2	133.7	21.5	30.6	46.9	1.5	7.1	0.141	0.310	0.455
16	SOVV7	1.4	147.8	122.5	21.7	30.1	46.9	1.5	7.1	0.164	0.300	0.547
6	SOVV7	1.5	149.5	133.0	21.4	29.7	46.9	1.5	7.0	0.153	0.281	0.544
19	SOVV7	1.6	149.6	132.8	21.5	30.0	47.0	1.5	7.1	0.135	0.289	0.467
21	SOVV7	1.7	148.6	118.9	21.7	30.7	47.0	1.5	7.1	0.145	0.309	0.469
20	SOVV7	1.9	149.1	124.7	21.8	30.6	46.9	1.5	7.1	0.140	0.309	0.453
7	SOVV7	2.0	149.3	134.4	21.9	30.4	47.1	1.5	7.1	0.137	0.310	0.442
15	SOVV7	2.0	148.2	119.8	22.4	30.9	47.1	1.5	7.1	0.164	0.343	0.478
3	SOVV7	2.3	149.1	126.6	22.3	31.2	46.4	1.6	7.1	0.140	0.334	0.419
8	SOVV7	2.4	148.8	133.3	22.3	31.2	46.9	1.5	7.1	0.135	0.314	0.430
2	SOVV7	2.8	149.0	124.1	23.0	31.6	46.5	1.6	7.1	0.170	0.373	0.456
9	SOVV7	2.8	149.7	126.7	22.8	31.3	46.7	1.5	7.1	0.138	0.340	0.406
14	SOVV7	2.8	149.0	113.0	23.5	33.8	46.9	1.5	7.1	0.223	0.378	0.590
10	SOVV7	3.2	149.7	122.0	23.7	33.5	46.9	1.5	7.1	0.144	0.360	0.400
1	SOVV7	3.4	148.3	120.7	24.4	32.8	46.5	1.6	7.7	0.153	0.395	0.387
11	SOVV7	3.8	149.8	120.1	25.1	36.1	46.9	1.5	7.1	0.162	0.403	0.402
13	SOVV7	4.3	150.2	132.1	26.3	37.9	46.7	1.5	7.1	0.259	0.453	0.572
12	SOVV7	4.5	147.9	95.8	26.8	38.3	47.2	1.5	7.1	0.229	0.453	0.506

Table 8.7

partial pe MEASUREMENTS FROM PHOTOS

					0.325						
Weld Inch	Plate Number	Plate Thickness	Magnif-ication	Measured Width	Measured Depth	Actual Width	Actual Depth	D/W Ratio	DELTAS************************** Width	Depth	Ratio
4	SOVV6	3.15	9.68	2.80	1.44	0.289	0.149	0.514	0.013	0.004	-0.011
19	SOVV6										
5	SOVV6										
3	SOVV6										
6	SOVV6	3.23	9.94	3.20	1.33	0.322	0.134	0.416	0.012	-0.006	-0.036
18	SOVV6	3.43	10.54	3.58	1.67	0.340	0.158	0.466	0.005	0.002	0.001
14	SOVV6	3.27	10.06	3.56	1.72	0.354	0.171	0.483	0.006	-0.003	-0.017
7	SOVV6										
1	SOVV6										
13	SOVV6										
16	SOVV6	3.32	10.20	3.99	1.92	0.391	0.188	0.481	0.002	0.003	0.006
17	SOVV6										
2	SOVV6	3.38	10.38	3.98	1.78	0.383	0.171	0.447	0.004	0.001	-0.001
15	SOVV6										
8	SOVV6	3.22	9.89	4.00	1.67	0.404	0.169	0.418	0.009	0.001	-0.008
12	SOVV6	3.54	10.89	4.43	2.37	0.407	0.218	0.535	-0.006	-0.001	0.005
9	SOVV6										
10	SOVV6	3.23	9.94	4.67	2.41	0.470	0.242	0.516	-0.001	-0.004	-0.006
11	SOVV6										
18	SOVV7										
17	SOVV7										
5	SOVV7										
4	SOVV7										
16	SOVV7										
6	SOVV7										
19	SOVV7										
21	SOVV7										
20	SOVV7										
7	SOVV7										
15	SOVV7										
3	SOVV7										
8	SOVV7										
2	SOVV7										
9	SOVV7										
14	SOVV7										
10	SOVV7										
1	SOVV7										
11	SOVV7										
13	SOVV7										
12	SOVV7										

Table 8.7

Inch	Number	(mm)	Forward (A)	Reverse (A)	Forward (V)	Reverse (V)	(scfh He)	(scfh Ar)	Speed (ipm)	Depth (")	Width (")	Ratio
19	SOVV8	1.3	149.9	135.4	21.8	30.4	121.5	1.5	7.1	0.146	0.308	0.474
2	SOVV8	1.5	149.7	136.3	21.5	30.8	116.9	1.6	7.1	0.149	0.303	0.492
18	SOVV8	1.8	150.0	134.3	22.1	31.3	121.2	1.5	7.1	0.143	0.335	0.427
20	SOVV8	1.8	149.5	132.2	22.1	30.9	121.9	1.5	7.1	0.132	0.314	0.420
3	SOVV8	2.1	149.1	125.7	21.7	31.3	117.7	1.6	7.1	0.152	0.269	0.565
4	SOVV8	2.3	149.1	121.4	21.9	31.5	118.4	1.6	7.1	0.126	0.311	0.405
17	SOVV8	2.6	148.8	124.7	22.9	31.7	121.2	1.5	7.1	0.157	0.361	0.435
1	SOVV8	2.8	149.2	125.6	22.7	32.0	112.6	1.7	7.9	0.134	0.332	0.404
16	SOVV8	3.1	148.3	113.0	23.8	34.3	121.1	1.5	7.1	0.207	0.385	0.538
5	SOVV8	3.2	149.5	123.2	22.7	32.4	119.0	1.6	7.1	0.130	0.343	0.379
21	SOVV8	3.2	149.4	124.0	23.5	34.2	121.9	1.5	7.1	0.126	0.370	0.341
6	SOVV8	3.8	149.3	119.2	23.9	34.6	119.3	1.6	7.1	0.129	0.386	0.334
15	SOVV8	4.2	148.7	98.8	25.5	37.5	121.2	1.5	7.1	0.240	0.413	0.581
7	SOVV8	4.5	149.2	103.3	25.0	36.8	119.6	1.6	7.1	0.156	0.437	0.357
8	SOVV8	5.3	149.5	94.5	26.2	40.0	119.9	1.5	7.1	0.190	0.455	0.418
14	SOVV8	5.3	149.1	100.5	26.6	40.1	120.9	1.5	7.1	0.252	0.453	0.556
9	SOVV8	5.5	148.5	86.0	26.6	41.5	120.4	1.6	7.1	0.250	0.511	0.489
10	SOVV8	6.0	149.8	113.7	27.2	39.5	120.2	1.5	7.1	0.245	0.472	0.519
13	SOVV8	6.0	149.4	100.5	27.4	41.2	121.0	1.5	7.1	0.250	0.468	0.534
11	SOVV8	6.7	149.3	115.8	27.8	40.0	120.5	1.5	7.1	0.238	0.500	0.476
12	SOVV8	6.7	149.6	103.8	28.0	40.4	120.9	1.5	7.1	0.253	0.485	0.522

Table 8.7

This data is for an VPPA weld on 2219 aluminum. The nominal values for constant parameters: 27V; 107A; 7.2 mm S-O; 2 scfh Ar Pgas; 12 ipm Wire Feed (.062" dia); 7.5 ipm Travel Speed

Sgas (He) was increased approximately linearly from 24 to 177 scfh over length of weld

Weld Inch	Width	Depth	D/W	D X W	Approx Sgas(scfh)	SGas / 300
1	0.370	0.137	0.370	0.0507	24.0	0.080
2	0.371	0.151	0.407	0.0560	31.7	0.106
3	0.384	0.167	0.435	0.0641	39.3	0.131
4	0.386	0.157	0.407	0.0606	47.0	0.157
5	0.370	0.147	0.397	0.0544	54.6	0.182
6	0.390	0.149	0.382	0.0581	62.3	0.208
7	0.421	0.150	0.356	0.0632	69.9	0.233
8	0.394	0.141	0.358	0.0556	77.6	0.259
9	0.379	0.136	0.359	0.0515	85.2	0.284
10	0.384	0.135	0.352	0.0518	92.9	0.310
11	0.377	0.136	0.361	0.0513	100.5	0.335
12	0.380	0.128	0.337	0.0486	108.2	0.361
13	0.379	0.120	0.317	0.0455	115.8	0.386
14	0.397	0.131	0.330	0.0520	123.5	0.412
15	0.382	0.127	0.332	0.0485	131.1	0.437
16	0.414	0.137	0.331	0.0567	138.8	0.463
17	0.398	0.136	0.342	0.0541	146.4	0.488
18	0.398	0.115	0.289	0.0458	154.1	0.514
19	0.365	0.104	0.285	0.0380	161.7	0.539
20	0.356	0.106	0.298	0.0377	169.4	0.565
21	0.384	0.108	0.281	0.0415	177.0	0.590

Table 8.8

9.0 Control Algorithm Development

The VPPA control algorithm was designed to maintain specified crown and root widths, given weld parameter measurements from the weld controller and optical sensor measurements of the crown width near real time. The weld parameters controlled by the VPPA control algorithm are power and speed. All other parameters, including gas flow rates and torch standoff, are assumed fixed. The algorithm has been successfully integrated and tested with a HAWCS-II controlled welding station, Weld Station 4, located in Building 4705 at NASA Marshall Space Flight Center in Huntsville, Al.

The VPPA control algorithm assumes that the significant uncertainty in the VPPA weld process is the efficiency with which power generated is delivered to the workpiece. If a weld is occurring 'nominally' then no close loop control is required. As perturbations occur, such as gradual changes to the torch, an optical sensor system was to have observed the resulting variation in crown width. The sensor measured crown width would then have been used by the VPPA control algorithm to estimate actual efficiency, and correspondingly adjusted the power and speed to maintain the scheduled crown and root widths.

Unfortunately, the optical sensor system did not perform adequately and no successful closed loop tests were performed. However, the control algorithm was used in open loop experiments as described in this report and produced predicted root and crown width accuracy's on the order of 0.015" RMS.

9.1 WELD MODEL

The VPPA control algorithm is based on an approximate model that is derived from a steady state solution to the linear (constant thermal properties) heat diffusion equation, i.e.

Weld width = (C1 / weld speed) * exp (C2 / power delivered to weld)

where

C1 = 4.5 * thermal diffusivity of weld metal

and

C2 = 2p * thermal conductivity of weld metal * thickness of plate * (melting temperature of metal - ambient temperature)

The power delivered to the weld, Pd, is related to the power generated by the welding apparatus through an efficiency:

Pd = Efficiency * Pg

The efficiency is not fixed, and is not well understood, but it can be related to Pg and weld speed by an approximate, empirical relation:

Efficiency = E0 + E1 * Pg + E2 * Weld Speed

Efficiency is observed to decline with increasing power at constant speed (E1 is negative) presumably because of greater loss of power through the keyhole. Efficiency increases with weld speed at constant power (E2 is positive) presumably because the forward interface of the keyhole slopes backwards so as to catch more of the beam per unit depth.

It may be possible to make the above relation universal rather than material specific by replacing Pg and weld speed by dimensionless quantities:

Pg > Pg / {2p * thermal conductivity of weld metal * width of plate * (melting temperature of metal - ambient temperature)}

and

Weld speed > weld speed /{ thermal diffusivity of weld metal / plate thickness}

This requires further study as different dimensionless groups would be required for different dominant mechanisms controlling efficiency (See Appendix VI by A. Nunes).

To extend the treatment to the usual situation where the weld crown and root have different widths, we imagine the plate split over its midplane. Each half plate (now with half the thickness of the original plate) is assumed to receive its own portion of the power delivered Pd. Alpha is defined as the distribution parameter including the factor dividing the plate into halves such that:

Crown power = Pd * (1 + alpha)

Root power = Pd * (1 - alpha)

Alpha has been defined so as to be positive for the usual case where the crown is wider than the root.

An empirical relation has also been worked out for the distribution parameter:

Alpha = A0 + A1 * Pg + A2 * Pd

This relation too should become universal when correctly nondimensionalized. The A1 and A2 parameters for 2219 aluminum could be converted to those for A36 mild steel to within 15% by use of the dimensionless group suggested above for Pg.

Thus six parameters (E0, E1, E2, A0, A1, A2) characterize the weld process. For the present purposes these parameters were obtained empirically from data obtained by a series of experimental weld runs on .250 thick 2219 aluminum using a non-linear least squares procedure (See VPPA Weld Model Evaluation, Final Report, July 31, 1992, NASA Contract No. NAS8-38812). It was planned to compute these parameters for other materials and thicknesses by use of the theoretical model developed with UAH, but problems with the model surfaced and prevented this (See Appendix V). As a weld station is relatively stable once set up, the six parameters for a specific situation should be obtainable from just a few initial test welds. This was the approach used in the open loop tests described below.

9.2 OPEN LOOP TESTING

Two sets of tests of the VPPA control algorithm were performed using the Vertical Tool, Weld Station 4, located in Building 4705 at NASA Marshall Space Flight Center in Huntsville, Al. The weld station consists of a HOBART HAWCS II weld control system controlling all tool motion, gas controls, power supply controls and torch motion. Switching a Keyence laser distance sensor for the Arc Voltage sensor used by the HOBART HAWCS II weld control system allowed closed-loop control of the torch height.

9.2.1 Open Loop test of Controller for 0.25" AL2219

Thermal properties used for AL2219 were:

Specific Heat	0.864	(W/g-deg K)
Conductivity	1.3	(W/cm-deg K)
Density	2.82	(g/cm3)
Melting Temp	916	(deg K)

Three calibration welds were run on 0.250" AL2219. The three test runs were made at slow, moderate and fast speeds. During each run, weld current was systematically changed. The resulting measurements were used to derive the six parameters used to define efficiency and distribution. The test results are presented in Appendix III including photocopies of the calibration welds.

The controller was designed to work with power as a parameter that could be controlled and the welder achieves this by changing weld current. As weld voltage varies with weld current a separate control logic is required to maintain the specified power. When using the model to generate weld schedules, an estimate of voltage is required to determined the requested current. The function used was

$$\text{voltage} = V0 + V1 * \text{power generated} + V2 * \text{speed}$$

and was accurate to within a few tenths of a volt, RMS. In the cases that the voltage prediction was not accurate, the width predictions were likewise in error. This supports the requirement that separate power control is necessary.

The value of weld voltage measured during the calibration welds used in adapting the controller to the weld station were considerably lower than those experienced in earlier experiments for AL2219. Thus, the controller generated from the model derived from a large number of earlier experiments would generate a large error in predicting crown and root width. Adapting the controller from calibration weld data provided an RMS prediction error 0.029" in the crown, 0.024" in the root and 0.027" overall. The residuals in the model fit indicated a second order power effect that was evident at slow speeds. To compensate for this, a term was added to the distribution parameter (alpha) of the form power squared divided by speed. This reduced the prediction error to 0.009" for the crown and 0.014" for the root and 0.011" overall for the calibration welds (see Appendix III). The cause of the voltage discrepancy is unknown, and is possibly due to a change in the electrode configuration.

A test plate was then made with a varied schedule and the model was used to predict the widths produced. The test schedule was chosen to be stressing and included values outside of the range used to generate the parameters. The results of the test weld and a photocopy of the test plate are provided at the end of Appendix III. The controller produced an RMS prediction error of 0.015" for the crown, 0.019" for the root and 0.017" overall.

9.2.2 Open Loop Test of controller for 0.200" AL2195

Thermal properties used for AL2195 were:

Specific Heat	1.255(W/g-deg K)
Conductivity	0.78 (W/cm-deg K)
Density	2.70 (g/cm3)
Melting Temp	911 (deg K)

Three calibration welds were run on 0.200" AL2195. The three test runs were made at slow, moderate and fast speeds. During each run, weld current was systematically changed. The resulting measurements were used to derive the six parameters required for the Controller. A check of the controller showed an RMS error of 0.15" in the crown, 0.15" in the root and 0.15" overall. A test plate was then made with a varied schedule and the model was used to predict the widths produced. The test schedule was chosen to be stressing and included values outside of the range used to generate the parameters. In some cases the weld was unacceptable such as cutting. The controller width prediction RMS error for the test plate was 0.13 in the crown, 0.72 in the root and 0.52 overall (see Appendix IV). This error is in part due to the inclusion of the section of weld where there was cutting. Exclusion of this section yields a large reduction in the root RMS error to 0.027" and the overall to 0.022". The results of the weld and a photocopy of the test plate are provided at the end of Appendix IV.

9.3 Test Results:

A graph of the relationship between the root and crown width with change in weld current for AL2219 is shown in Figure 9.1 and AL2195 is shown in Figure 9.2. One significant difference noted between AL2219 and AL2195 was that is relatively easy to produce welds with AL2195 where the root is significantly larger than the crown. It is not known if this is a result of differences in material properties or the back side purge used for the AL2195. This is shown in the graph of Figure 9.2 where the root width and crown width cross showing the root becomes larger than the crown.

It is possible that the weld fixture has an effect on the weld geometry and repeatability of welds from one weld tool to another. The VPPA control algorithm may be able to quantify these differences by performing a set of test welds as performed in this study

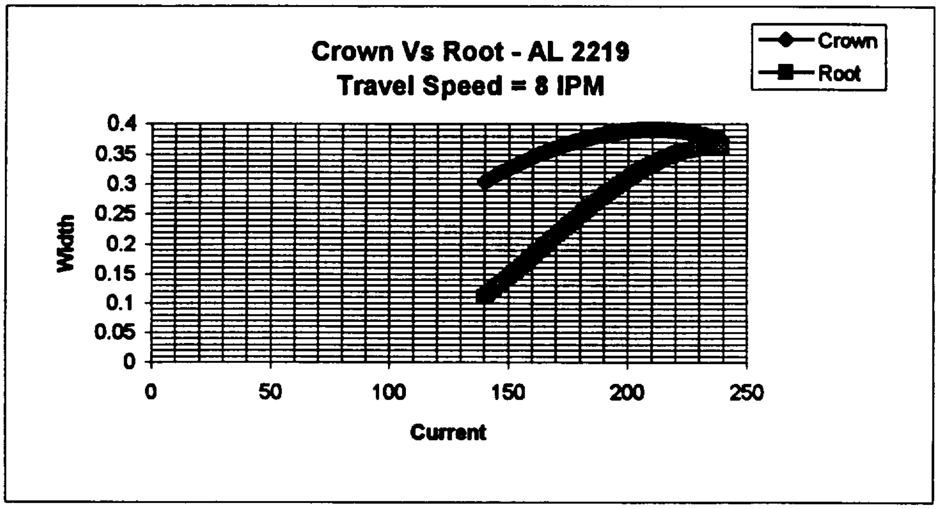

Figure 9.1 AL2219 Root and Crown Width VS Weld Current (Travel Rate = 8 IPM)

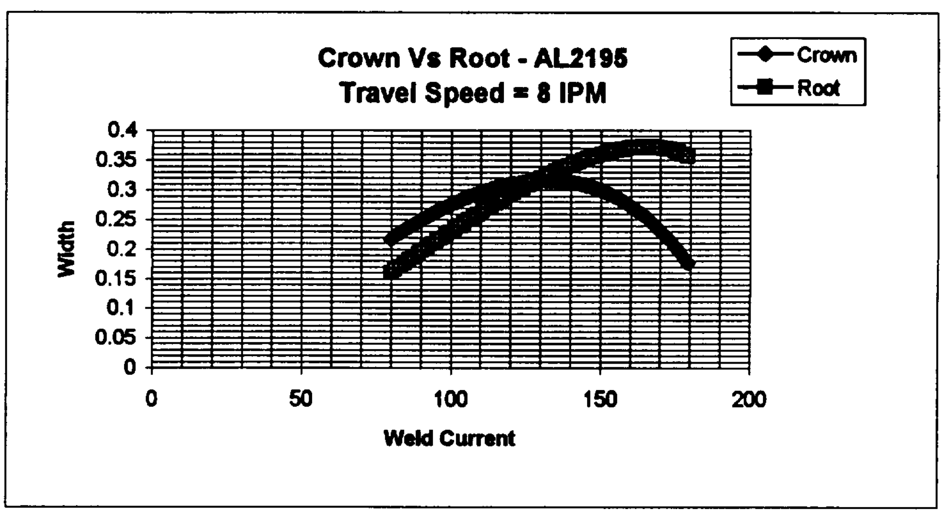

Figure 9.2 AL2195 Root and Crown Width VS Weld Current (Travel Rate = 8 IPM) w/ Backside Purge Chamber

9.4 CONCLUSION AND RECOMMENDATIONS

Until an optical sensor is available to measure crown width, the control logic can be used to generate weld schedules that can be expected to produce welds within the tolerances given in appendices III and IV. Possible applications include:

1. Determining optimum weld geometry. By generating a systematic range of weld shapes and then testing the welds for strength, the 'best' geometry could be estimated for various weld configurations. For this purpose, a cover pass dimension would have to be introduced, and the control model extended to include wire feed and crown/root height.

2. Optimum welds for materials of varying thickness. By producing a composite model for a range of thickness (perhaps using the 'normalized' variable mentioned above), a calculus of variations approach could be used to generate optimum schedules that would make the 'best' continuous adjustments to changes in material thickness.

Appendix I

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REPORT NO. NRC-TR-95-017

GEOMETRY EFFECTS ON FLOW AND FRACTURE STRESSES IN BUTT WELDS

1 February 1995

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SECTION 1. INTRODUCTION

This report documents the weld geometry effects theory proposed by Dr. Arthur C. Nunes, Jr. to predict the onset of flow and fracture in a welded plate. This theory represents an extension of slip line theory from homogeneous to non-homogeneous structures. The intent of the efforts documented herein has been to use the Nunes theory to develop a simple handbook type analytical model which can be used to predict the onset and location of flow and the subsequent elongation and fracture of the structure.

Section 2 of the report discusses the development of the theory for a uniform width weld with tapered sides and no reinforcement. Equations are developed which can be used to calculate the flow and fracture loads, and results are compared to test data. In Section 3 the theory is extended to welds with reinforcement and tapered sides. In subsequent studies the model will be refined and extended to include the effects of peaking and offsets. Observations and recommendations are presented in Section 4.

SECTION 2. UNIFORM WIDTH WELD

2.1 GEOMETRY AND NOMENCLATURE

An unreinforced uniform width weld is shown in Figure 1. The weld width is w and the plate thickness is t. The weld is subjected to a tensile load σ per unit area of parent metal cross section. The horizontal dimension, x, is measured from the centerline, and the vertical dimension, y, is measured from the root (bottom) of the weld. Consistent with slip line theory in isotropic materials and limited observations of flow in welds carried out by R. Arrowood et. al. at the University of Texas in El Paso (Reference 1), it is assumed that material flow will occur along planes which are oriented at 45° to the load direction. Because of continuity, slip must be constant along the entire length of each slip line. Consequently, on each slip line, no slip occurs until the entire line has reached the flow stress. The parameters ξ_r and ξ_l designate the x component of the root intercepts of right and left sloping slip lines. It is assumed that the dimension normal to the page in Figure 1 is large, so all motion occurs in the plane of the page. That is, there will be x and y components of displacement, but no z components. For any point in a plate section the total strain will be the sum of the strain due to the two orthogonal slip lines passing through the point.

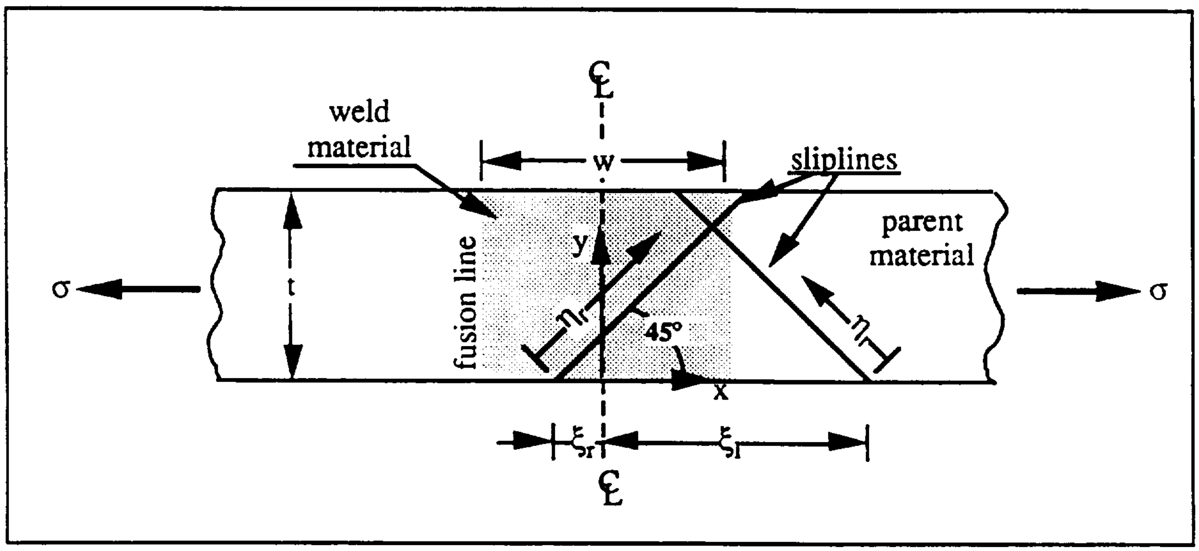


Figure 1. Uniform Weld Geometry Nomenclature

2.2 FLOW INITIATION STRESS

Because of the symmetry of the problem, flow initiation for a square weld section will occur symmetrically about the weld centerline. The location of flow initiation will depend on the geometry of the welded plate and on the flow stress in the weld and parent materials. In the present formulation the flow stress is assumed to behave according to Equation 1.

$$\sigma_f = \frac{\sigma_w + \sigma_p\left(\frac{2x}{w}\right)^{2k}}{1+\left(\frac{2x}{w}\right)^{2k}} \tag{1}$$

where:

$\sigma_f =$	Composite flow stress function
$\sigma_w =$	Weld material flow stress
$\sigma_p =$	Parent material flow stress
$k =$	Positive integer characterizing the transition of σ_f from σ_w to σ_p
$w =$	Effective weld width, at which $\sigma_f = (\sigma_w + \sigma_p)/2$

The factors of 2 in the exponents in the numerator and the denominator of Equation 1 assure that σ_f will be an even function and thus be symmetric about the weld centerline. The effective width, w, is the width at which $\sigma_f = (\sigma_w + \sigma_p)/2$. This effective width may not be the same as the fusion zone width, but in most cases they can be expected to be of similar magnitude. Figure 2 shows plots of σ_f for $\sigma_w = 25$, $\sigma_p = 50$, $w = 1$ and $k = 1$ through 4. For $k = 1$ the curve has an upside down bell shape. As k increases the bell takes on a more rectangular shape, until in the limit of infinity it becomes an inverted top hat.

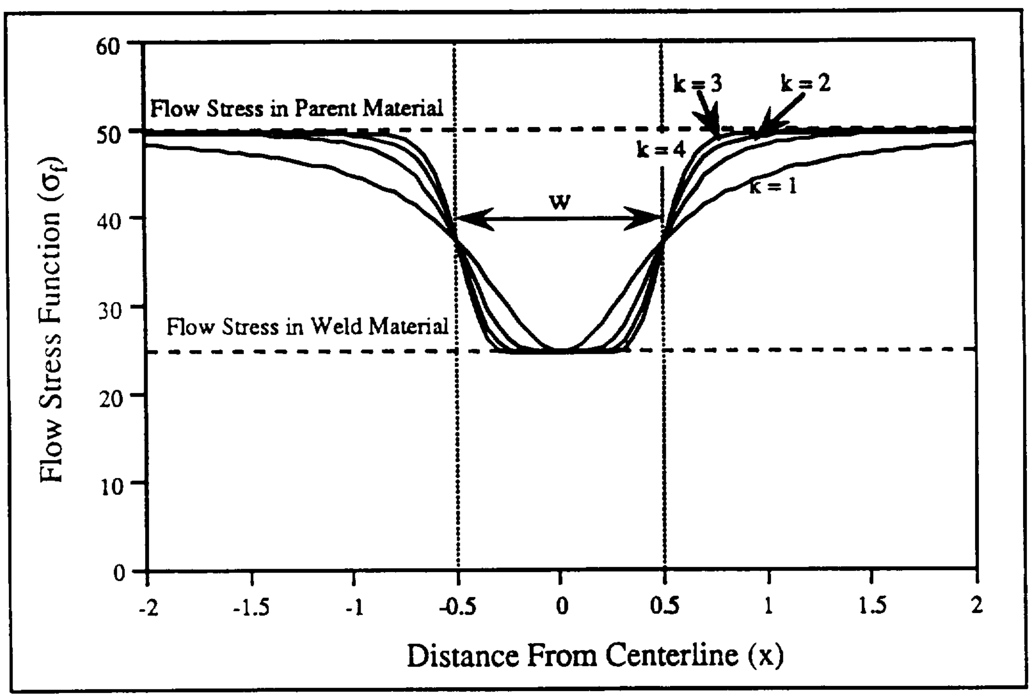


Figure 2. Flow Stress Function (σ_f) for $\sigma_p = 50$, $\sigma_w = 25$

Figure 3 shows a free body diagram of a weld sectioned along an arbitrary right sloping slip line. The coordinate ξ_r represents the distance along the root surface of the weld metal plate in the x direction from the weld centerline to the slip line of interest. The coordinate η_r lies along the slip line. The applied stress σ and the normal and shear components of stress on the slip line are σ_n and τ respectively. The relationship between σ_n and τ is established by summing the vertical forces on a section of the free body with a vertical dimension of dy and a dimension into the page of unity (Equation 2).

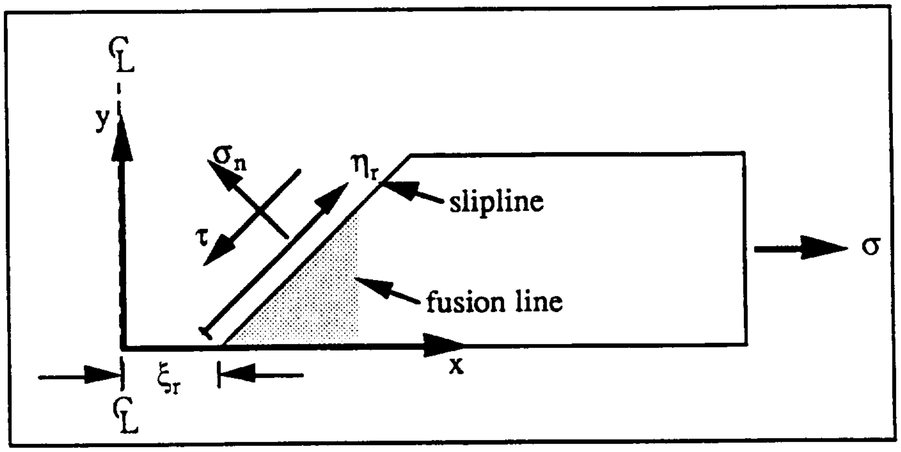


Figure 3. Free Body Diagram of Weld Sectioned Along an Arbitrary 45° Plane

$$\sum F_v = \left[(\sigma_n d\eta_r)\cos 45° - (\tau d\eta_r)\sin 45°\right] = 0$$

$$\therefore \sigma_n = \tau \qquad (2)$$

The relationship between the external load (σ) and the shear stress (τ) is obtained by summing the horizontal forces.

$$\sum F_h = \left[(\sigma_n d\eta_r)\sin 45° - (\tau d\eta_r)\cos 45°\right] d\eta_r - \sigma dy = 0$$

$$= \left[\sigma_n \frac{dy}{\sin 45°}\right]\sin 45° + \left[\tau \frac{dy}{\sin 45°}\right]\cos 45° - \sigma dy$$

$$\sigma_n + \tau - \sigma = 0$$

But from Equation 2 we know that $\sigma_n = \tau$.

$$\therefore \sigma = 2\tau \qquad (3)$$

Equations 2 and 3 were derived from the free body diagram in Figure 3 showing a slip line sloping upward to the right. The same relations are obtained for a left sloping slip line. Distance along the slip lines, η_r and η_l are numerically equal, and in all of the following equations may be used interchangeably. Therefore in subsequent derivation the subscript of η has been dropped.

Flow conditions will exist locally when the shear stress at a point reaches the material flow stress $\sigma_f = 2\tau$. Per slip line theory, no displacement will occur anywhere on a slip line until every point on the line has reached the flow stress. The external load at which displacement will begin to occur is calculated by integrating the horizontal force equilibrium equation over the length of the slip line.

$$\int_0^t \sigma\, dy = \int_0^{t\sqrt{2}} \sigma_n \sin(45°) d\eta + \int_0^{t\sqrt{2}} \tau \cos(45°) d\eta$$

From St. Venant's principle σ can be assumed to be constant for all values of y, and from Equation 2, $\sigma_n = \tau$.

$$\sigma\, t = \frac{2}{\sqrt{2}} \int_0^{t\sqrt{2}} \tau\, d\eta$$

Displacement along the slip line begins when $\sigma = \sigma_f = 2\tau_f$.

$$\sigma_{fi} = \frac{1}{t\sqrt{2}} \int_0^{t\sqrt{2}} \sigma_f d\eta \tag{4}$$

Where σ_{fi} is the flow initiation load.

Substituting Equation 1 into Equation 4 gives:

$$\sigma_{fi} = \frac{1}{t\sqrt{2}} \int_0^{t\sqrt{2}} \left[\frac{\sigma_w + \sigma_p \left(\frac{2x}{w}\right)^{2k}}{1 + \left(\frac{2x}{w}\right)^{2k}} \right] d\eta \tag{5}$$

To evaluate the integral of Equation 5 for slip lines sloping upwards to the right, let $x = \xi_r + (\eta/\sqrt{2})$ and use the substitution $u = (2/w)(\xi_r + (\eta/\sqrt{2}))$. For left sloping slip lines use $x = \xi_l - (\eta/\sqrt{2})$ and $u = (2/w)(\xi_l - (\eta/\sqrt{2}))$. This substitution changes the integration limits from $\eta = 0$ and $t\sqrt{2}$ to $u = 2\xi/w$ and $(2/w)(\xi_r + t)$ respectively for right sloping lines. For left sloping slip lines the limits become $u = 2\xi/w$ and $(2/w)(\xi_l - t)$. Finally, the value of the exponent coefficient (k) must be set to 1. This value of k is necessary to obtain a closed form solution. Evaluation of Equation 5 results in an expression for the flow initiation stresses for right and left sloping lines ($\sigma_{fi\text{-}r}$ and $\sigma_{fi\text{-}l}$) in the weld as a function of applied stress, flow stress of the component materials and weld geometry.

$$\sigma_{fi\text{-}r} = \sigma_p - \left(\sigma_p - \sigma_w\right)\left[\frac{w}{2t}\left(\tan^{-1}\frac{2(\xi_r + t)}{w} - \tan^{-1}\frac{2\xi_r}{w}\right)\right] \tag{6}$$

$$\sigma_{fi\text{-}l} = \sigma_p - \left(\sigma_p - \sigma_w\right)\left[\frac{w}{2t}\left(\tan^{-1}\frac{2\xi_l}{w} - \tan^{-1}\frac{2(\xi_l - t)}{w}\right)\right] \tag{7}$$

The second term on the right side of Equations 6 and 7 is a stress deficit distribution function which defines the amount by which the weld material reduces the flow stress below that of the parent material. Also note that ξ_r and ξ_l are the only unknown parameters in Equations 6 and 7.

As the external applied load (σ) is increased, flow will begin at the point where σ_{fi} is a minimum. This minimum is determined by differentiating Equations 6 and 7 with respect to ξ and setting the derivative to zero. For the right sloping slip lines the evaluation is as follows.

$$\frac{d\sigma_{fi\text{-}r}}{d\xi_r} = \left(\sigma_p - \sigma_w\right)\frac{d}{d\xi_r}\left\{\frac{w}{2t}\left[\tan^{-1}\frac{2(\xi_r + t)}{w} - \tan^{-1}\frac{2\xi_r}{w}\right]\right\} = 0 \qquad (8)$$

Solving Equation 8 thus reduces to setting the derivative of the term in braces to zero.

$$\frac{d}{d\xi_r}\left\{\frac{w}{2t}\left[\tan^{-1}\frac{2(\xi_r + t)}{w} - \tan^{-1}\frac{2\xi_r}{w}\right]\right\} = 0 \qquad (9)$$

$$\begin{aligned} (t+\xi_r)^2 &= \xi_r^2 \\ t+\xi_r &= \pm\xi_r \end{aligned} \qquad (10)$$

The only physically acceptable option yielded by Equation 10 is $\xi_r = -t/2$. For a left sloping slip line the corresponding root coordinate for the slip line is $\xi_l = +t/2$. The two resulting slip lines are symmetric about the weld centerline and about the midplane of the plate (Figure 4). This suggests that the formulation could be simplified by shifting the origin of the coordinate system used in the integration from the root to the midplane. It was decided to use the present coordinate system because in subsequent investigations of welds with tapered widths the symmetry about the midplane will disappear, making the integration more complex.

The initial flow stress is plotted as a function of ξ_r for right sloping slip lines (Equation 6) in Figure 5. This figure shows that the minimum $\sigma_{fi\text{-}r}$ occurs at $\xi_r = -t/2$. Figure 5 also shows that as the width of the weld becomes large (t/w becomes small) the initial flow stress approaches σ_w. This is consistent with intuition, since a very wide weld would correspond to a plate in which the parent material is wholly replaced by the weld material. Conversely, as the weld becomes very narrow (t/w becomes large) σ_{fi} approaches σ_p and, although the location of ξ remains at -t/2, the minimum of the curve is not as well defined as for the wider welds. This is a consequence of the fact that as the weld becomes narrower, it represents an increasingly smaller fraction of the total length of the slip line.

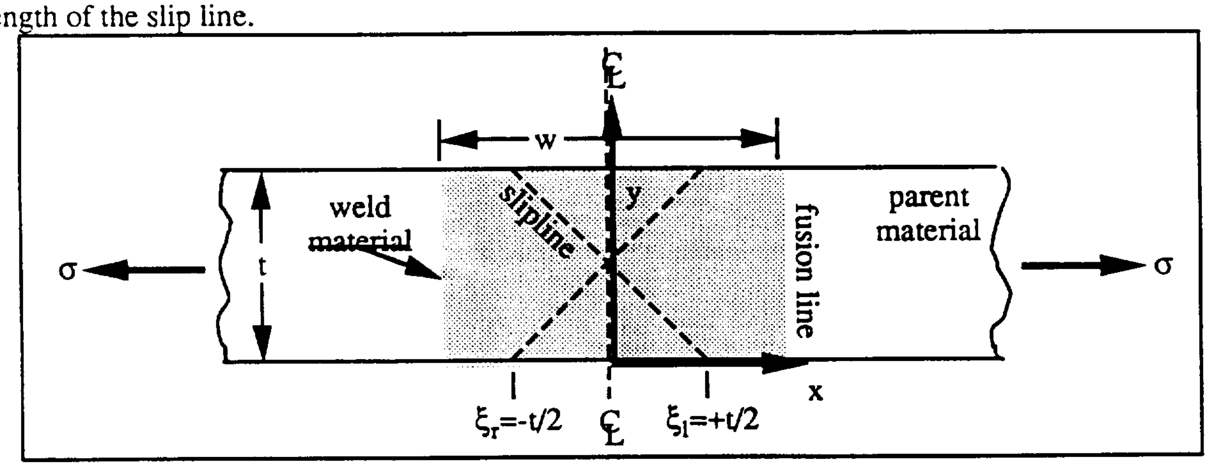


Figure 4. Minimum Flow Stress Slip Lines

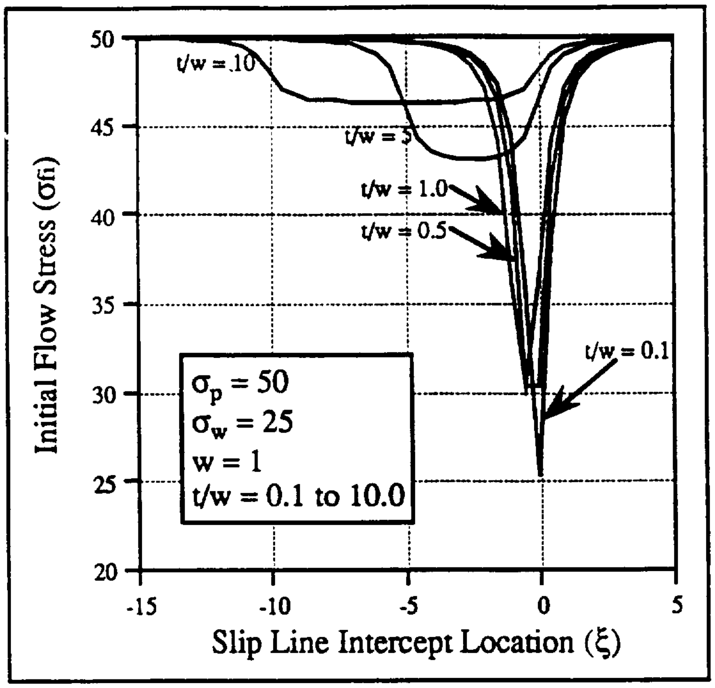


Figure 5. Initial Flow Stress Vs Slip Line Intercept Location

2.3 ELONGATION AND STRAIN HARDENING

Given the location of slip initiation, the region of slip must be quantified. This region is dependent on the strain ε that occurs in the x direction due to slip along the slip lines. Strain hardening of the material due to slip will be included using the linear strain hardening parameter α. A rigidly plastic constitutive model with constant linear strain hardening in a non-homogeneous material is shown in Figure 6. The curve in this figure differs from that for a homogeneous material in that it has a knee that separates the regions where only one of the slip lines is active.

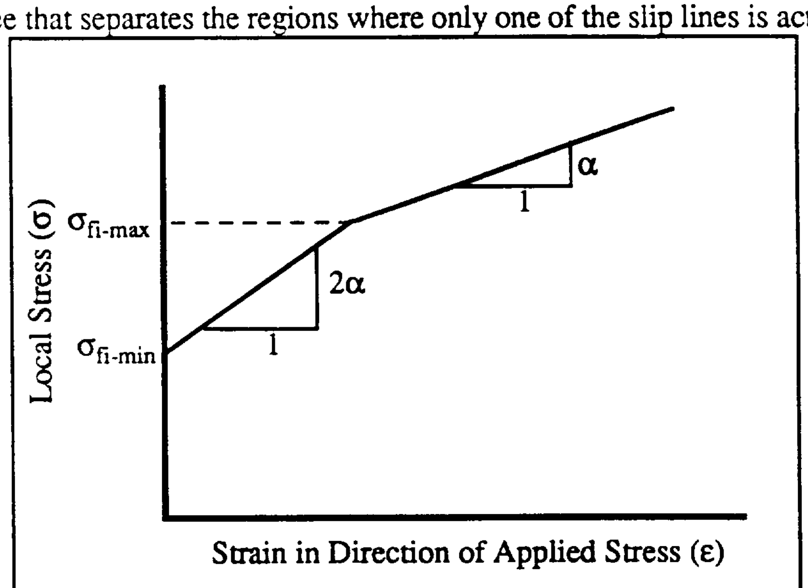


Figure 6. Rigidly Plastic Linear Strain Hardening Constitutive Model

The values of $\sigma_{fi\text{-}min}$ and $\sigma_{fi\text{-}max}$ in Figure 6 are calculated from Equations 6 and 7. The total strain at any point in the structure is the sum of components from the right and left sloping slip lines. From the constitutive model for strain hardening in Figure 6, the strain in each of the three regions are calculated from Equations 11 through 14.

If $\sigma < \sigma_{fi\text{-}r}$: $$\varepsilon_r = 0 \tag{11}$$

If $\sigma \geq \sigma_{fi\text{-}r}$: $$\varepsilon_r = \frac{1}{2\alpha}\left(\sigma - \sigma_{fi-r}\right) \tag{12}$$

If $\sigma < \sigma_{fi\text{-}l}$: $$\varepsilon_l = 0 \tag{13}$$

If $\sigma \geq \sigma_{fi\text{-}l}$: $$\varepsilon_l = \frac{1}{2\alpha}\left(\sigma - \sigma_{fi-l}\right) \tag{14}$$

Substituting Equations 6 and 7 for σ_{fi} in Equations 11 through 12 yields the following strain for right and left sloping slip lines.

$$\varepsilon_r = \frac{1}{2\alpha}\left\{\sigma - \left[\sigma_p - \left(\sigma_p - \sigma_w\right)\frac{w}{2t}\left(\tan^{-1}\frac{2(\xi_r + t)}{w} - \tan^{-1}\frac{2\xi_r}{w}\right)\right]\right\} \tag{15}$$

$$\varepsilon_l = \frac{1}{2\alpha}\left\{\sigma - \left[\sigma_p - \left(\sigma_p - \sigma_w\right)\frac{w}{2t}\left(\tan^{-1}\frac{2\xi_l}{w} - \tan^{-1}\frac{2(\xi_l - t)}{w}\right)\right]\right\} \tag{16}$$

The total strain at any point in the structure is obtained by adding the contributions from Equations 15 and 16. For points on the root surface where $x = \xi_r = \xi_l$, the combination follows directly. For interior points it is necessary to determine the root intercepts of the respective slip lines.

In interpreting Equations 15 and 16 it is important to remember that these strains correspond only to plastic flow strains. The elastic strain which occurs prior to the onset of flow ($\sigma = \sigma_{fi}$) is much lower in magnitude, and is not considered here (see Figure 6). If Equation 15 or 16 yields a negative strain for a positive applied load this indicates that the slip line being considered is not active, so the plastic strain for that slip line must be set to zero.

Figure 7 shows surface strain values for a case with $\sigma_p = 50$, $\sigma_w = 20$, $\alpha = 65$, $t = 1.0$ and $w = 0.5$. Per Equation 10, the root intercept positions for initial flow are at $\xi_r = -t/2 = -0.5$ and $\xi_l = t/2 = 0.5$ for this example. Flow will initiate at these two locations at $\sigma = 33.39$ (Equations 6 and 7). Below this stress level there is no (plastic) strain. At $\sigma = 35$ strain is seen in the vicinity of the two slip line intercepts. At other points on the surface the strain remains zero. This is illustrated qualitatively in Figure 8. This figure corresponds to flow due to an external stress just above σ_{fi}, in which flow has occurred near the intercept points on the upper and lower surfaces. As the external stress is increased, the familiar necking pattern observed in tensile specimens develops. Note that when the initial flow stress is first reached, the maximum strain in the structure does not occur at the surface. It occurs at x = 0, y = t/2 which is the point at which the two active slip lines intersect.

Increasing the external stress beyond the initial flow level causes the regions of surface strain to expand in range and magnitude, eventually overlapping. When the external stress exceeds the flow stress of the parent material ($\sigma_p = 50$ in the present example) flow will exist in all parts of the structure. Increasing the external stress beyond this level will result in a uniform increase in the strain level throughout the structure.

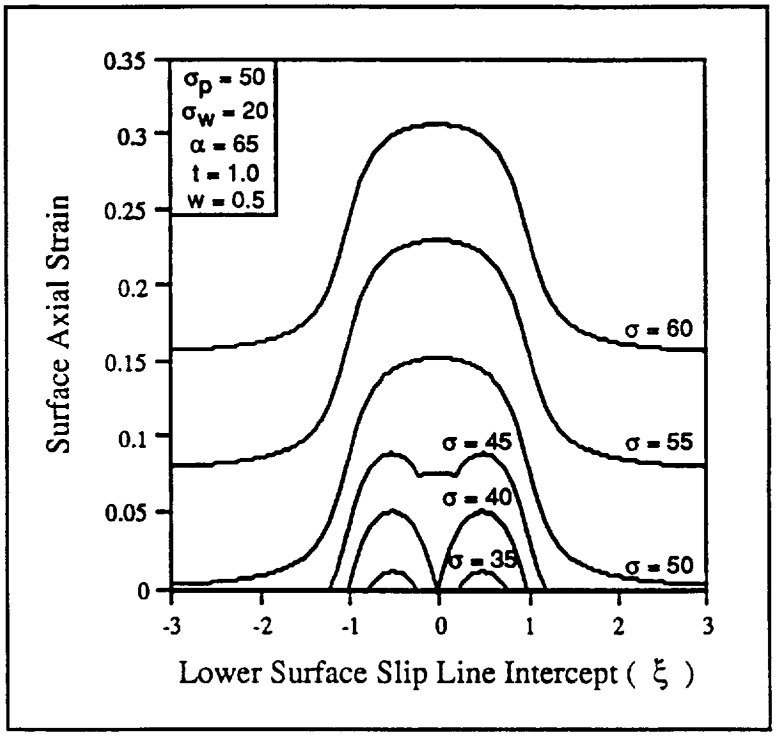


Figure 7. Surface Strain As a Function of Intercept Location and Applied Stress

2.4 FRACTURE STRESS AND LOCATION

The fracture stress in the vicinity of the weld is assumed to follow a function similar in form to that used for the flow stress in Equation 1.

$$\sigma_{fr} = \frac{\sigma_{frw} + \sigma_{frp}\left(\frac{2x}{w}\right)^{2n}}{1+\left(\frac{2x}{w}\right)^{2n}} \tag{17}$$

Where:

σ_{fr} = Composite fracture stress

σ_{frw} = Fracture stress at center of weld

σ_{frp} = Fracture stress in parent material

n = Positive integer characterizing the transition of σ_{fr} from σ_{frw} to σ_{frp}

w = Effective weld width at which $\sigma_{fr} = (\sigma_{frw} + \sigma_{frp}) / 2$

The factor n, like the factor k in the flow stress function, determines the "steepness" of the transition between parent and weld material properties.

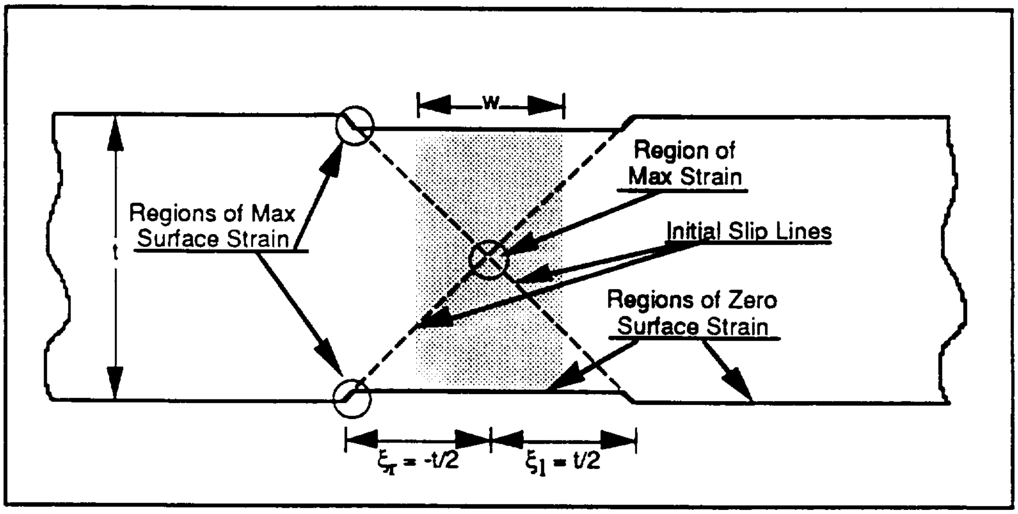


Figure 8. Displacement Pattern At Onset of Material Flow

It is further assumed that the fracture will initiate on the surface of the welded plate and propagate from there. The fracture initiation will occur at the first point on the surface where the local stress exceeds the local fracture stress.

If the externally applied stress is below the lowest flow stress everywhere in the structure, there will be no plastic deformation, so there will be constant uniform stress throughout the structure. Once the flow stress is exceeded anywhere in the welded plate there will be a redistribution of stresses along the affected slip lines to assure equilibrium with the external load. This will result in local stresses greater than the average of the applied stress. In general the total local stress will be the sum of the flow initiation stress and the strain hardening stress. The flow initiation stress is equal to the flow stress function shown in Equation (1). The strain hardening stress is obtained by multiplying the total strain (See Equation 10 through 16) by the strain hardening coefficient (α). The local stress σ_L is thus given by Equation 18.

$$\sigma_L = \left[\frac{\sigma_w + \sigma_p \left(\frac{2x}{w} \right)^2}{1 + \left(\frac{2x}{w} \right)^2} \right] + \alpha[\varepsilon_r + \varepsilon_l] \tag{18}$$

The problem now reduces to finding the lowest applied stress (σ) in Equation 18 which results in a local stress (σ_L) which intersects the fracture stress (σ_{fr}) defined in Equation 17. These equations are not readily amenable to a closed form algebraic solution, but the problem is easily solved numerically using spread sheet application software, as shown in Figure 9. The case investigated in Figure 9 uses data for 2219-T87/2319 VPPA butt welded aluminum (Reference 2). In reviewing this figure it is seen that there are regions in the vicinity of the weld where the local stress exceeds the applied stress. This can be thought of as a plastic stress concentration effect, which is analogous to the stress concentration associated with geometric discontinuities such as notches and holes. The factor n in the fracture stress function (Equation 17) was set to 1 in the calculations used for the plots of Figure 9. Figure 10 shows the effects of varying n from 1 to 4. At values of 2 and greater the fracture stress curve develops steeper sides and a more square bottom, allowing it to dip further into the well formed by the surface stress curve. As this happens the fracture initiation site moves from ±0.70 (outside the weld zone) to ±0.4 (inside the weld zone). Note that for all of the curves in Figures 9 and 10 k was set to 1 for the flow stress function.

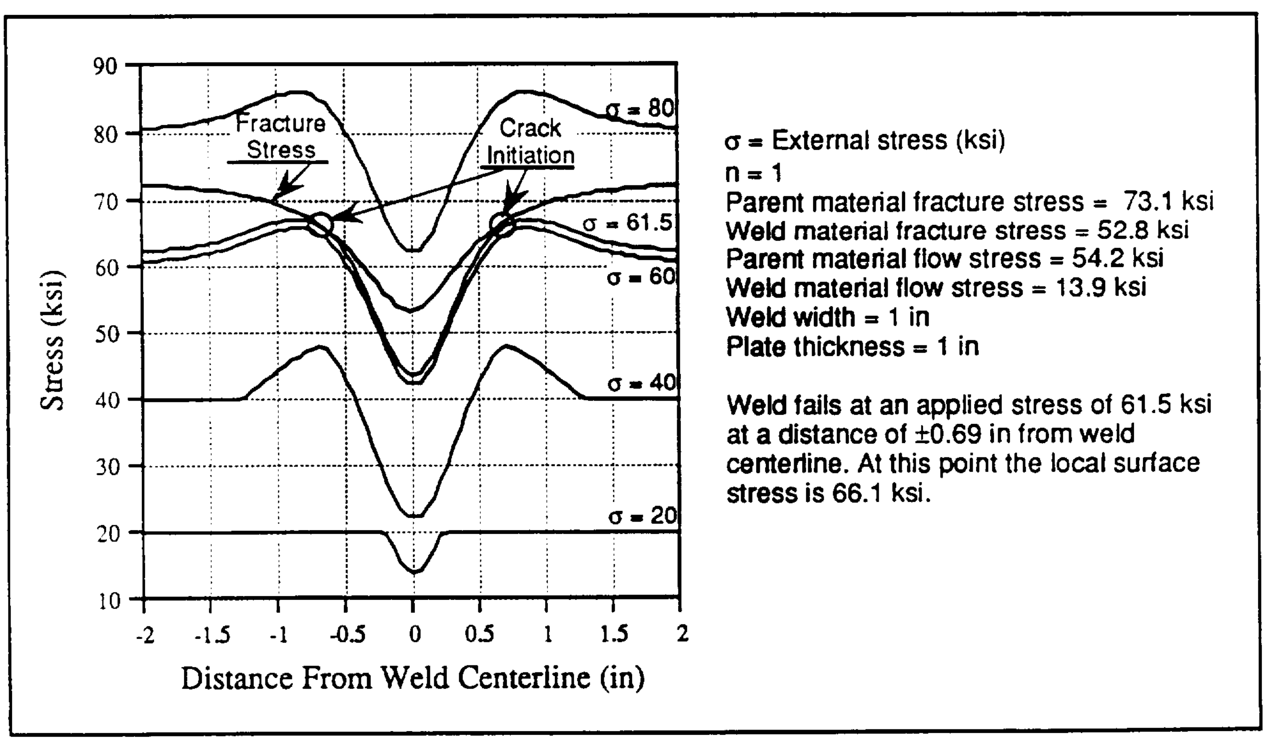


Figure 9. Local Surface Stress and Fracture Stress vs. Distance From Weld Centerline

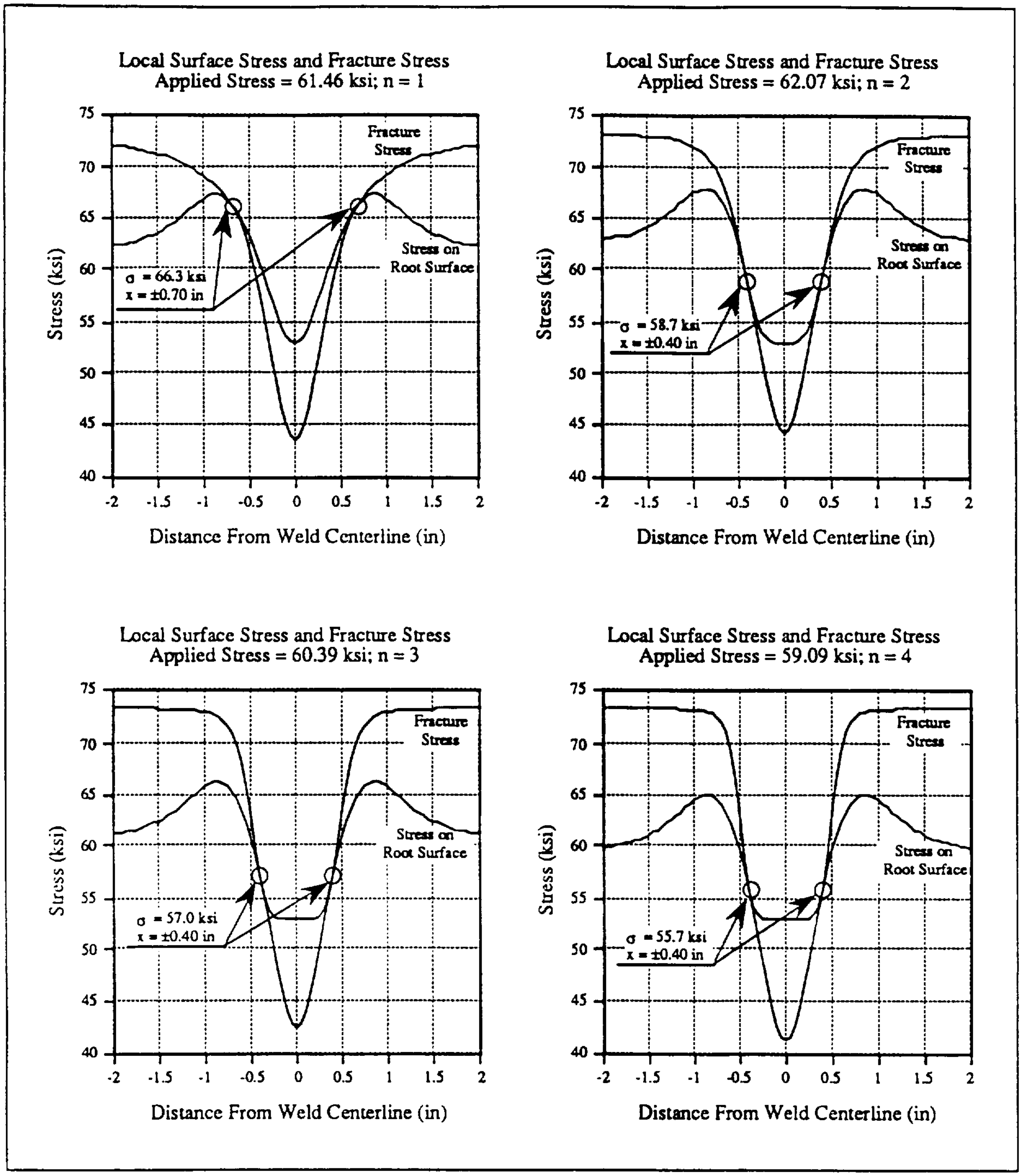


Figure 10. Effects of n-factor on Fracture Stress Magnitude and Location

Figure 11 shows a comparison of model data with test data for yield stress, ultimate tensile stress (i.e., fracture stress) and elongation. The material properties used in the cases plotted in Figure 11 were obtained from Reference 2 and the test data are from Reference 3. Welds in Figure 11 noted as made under "heat sink" conditions were made by sandwiching three quarter-inch plates together during welding and subsequently machining the plates apart. The model data shows curves which are similar in shape and magnitude to the test data, although there are some discrepancies. The discrepancies for yield (or flow) stress may be partially attributed to the use of k=1 in the flow stress function. A higher value would give a steeper shape to the curve, which would in turn lead to a greater influence of the softer weld material on the structure's flow stress. Setting k to a higher value in the flow stress function will require use of a numerical integration technique. The decrease in the fracture stress for thin welds may be attributable to the fact that both the fracture and flow stress functions require that the material characteristics at the weld center be independent of the weld width. This may not be a valid assumption for thin welds.

Finally the discrepancies in Figure 11 can be expected to be partly due to the fact that the welds had some reinforcement and tapered sides. The following section discusses work performed to formulate a model for such a weld geometry.

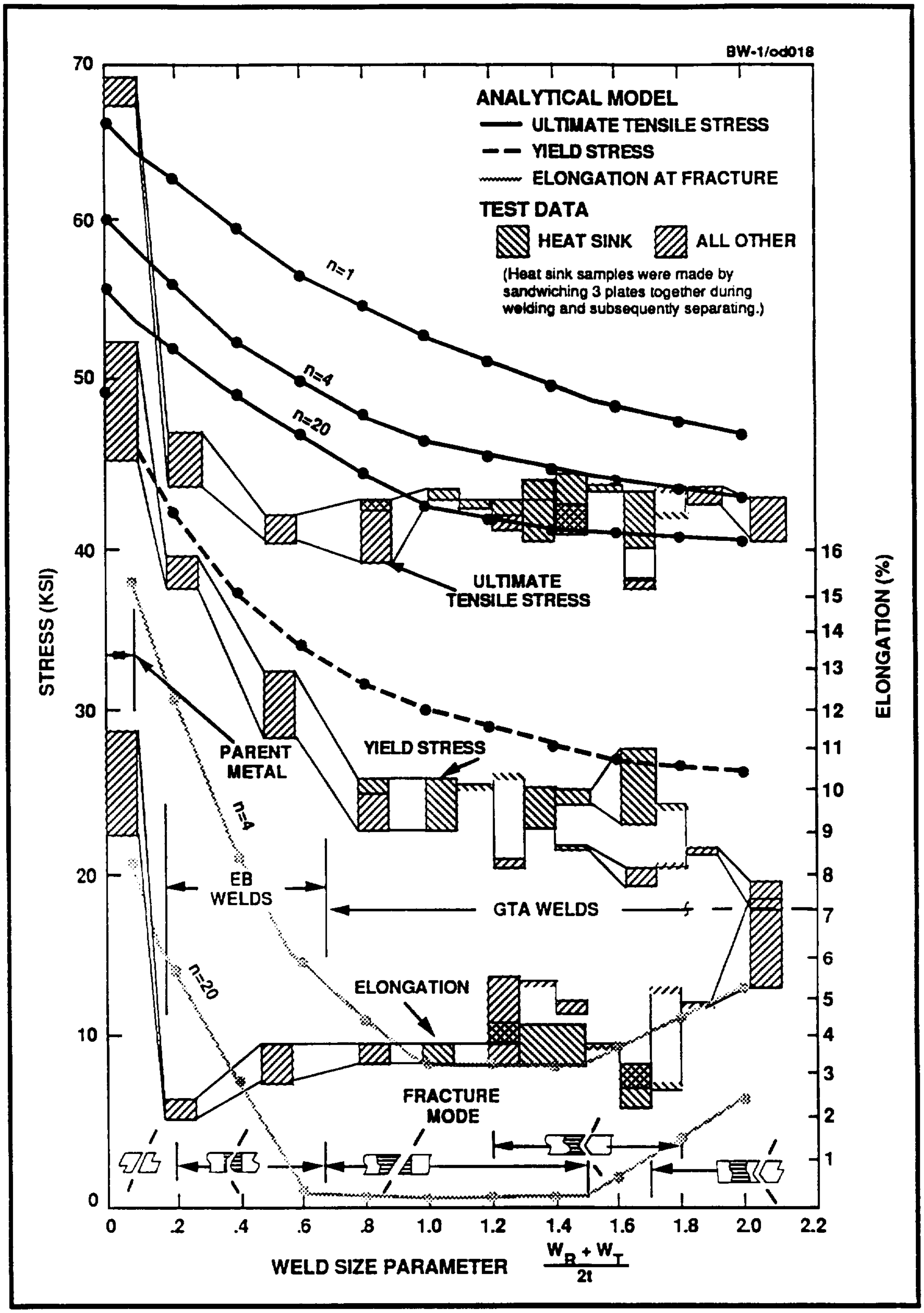


Figure 11. Comparison of Model and Test Data

SECTION 3. TAPERED WELDS WITH REINFORCEMENT

3.1 GEOMETRY AND NOMENCLATURE

A reinforced tapered width weld is shown in Figure 12. The root surface weld width and weld reinforcement are designated as w_r and δ_r respectively. The corresponding parameters on the crown surface are w_c and δ_c. The root intercepts of right and left sloping slip lines are designated by the variables ξ_r and ξ_l outside the reinforcement region. Within the reinforcement these variables designate the point at which the slip lines intersect the y = 0 surface—i.e., the point where the intercept would occur if there were no reinforcement. The variables ξ'_r and ξ'_l are used to designate the actual root intercept points. Outside the reinforced region $\xi_r = \xi'_r$ and $\xi_l = \xi'_l$. The variables ξ''_r and ξ''_l are used to designate the crown surface intercepts.

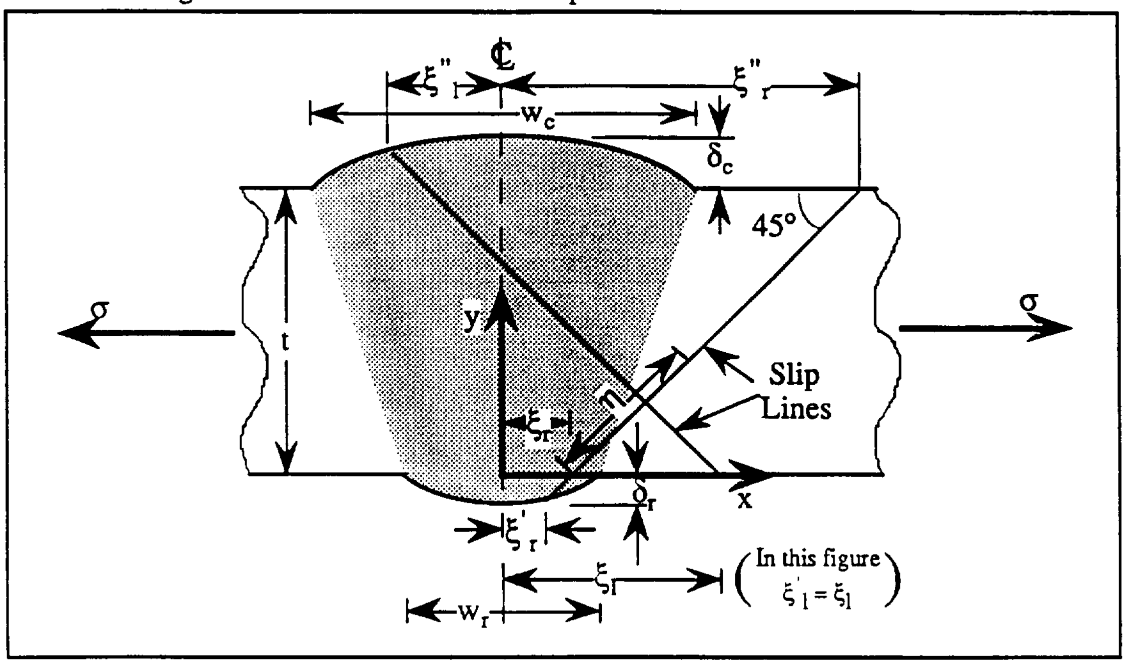


Figure 12. Tapered, Reinforced Weld Nomenclature

The surface of the root reinforcement regions are assumed to be defined by the following parabolic relations.

$$\text{If } x < -\frac{w_r}{2} \text{ or } x > \frac{w_r}{2} \qquad y = 0 \tag{19}$$

$$\text{If } -\frac{w_r}{2} < x < \frac{w_r}{2} \qquad y = \delta_r\left[\frac{4x^2}{w_r^2} - 1\right] \tag{20}$$

For the crown surface the following equations are assumed.

$$\text{If } x < -\frac{w_c}{2} \text{ or } x > \frac{w_c}{2} \qquad y = t \tag{21}$$

If $-\frac{w_c}{2} < x < \frac{w_c}{2}$

$$y = (\delta_c + t)\left[1 - \frac{4x^2}{w_c^2}\right] \tag{22}$$

3.2 FLOW INITIATION STRESS

In Section 2 it was shown that the material will begin to flow when the externally applied load, σ, reaches the value σ_{fi} as defined in Equation 4. In the case of a reinforced weld the same equation applies, but the integration limits must be adjusted to allow for the modified geometry.

$$\sigma_{fi} = \frac{1}{t\sqrt{2}} \int_{\eta_{min}}^{\eta_{max}} \sigma_f d\eta \tag{23}$$

The integration limits, η_{min} and η_{max} are defined by the points at which the slip lines intersect the root and crown surfaces of the plate. For the unreinforced portions of the structure these limits remain at 0 and $t\sqrt{2}$ respectively for both right and left sloping lines as used in Section 2. In the reinforcement regions the x coordinates of the root and crown intersections are defined as ξ_r', ξ_l', ξ_r'' and ξ_l'', as shown in Figure 12. The values of the intersection points and the corresponding η_{max} and η_{min} values are given in Equations 24 through 31. It is important to recall that the integration limits defined in Equations 24 through 31 apply only to slip lines terminating in the reinforced region. Outside this region the limits revert to 0 and $t\sqrt{2}$.

Root Surface, Right Slope:

$$\xi_r' = \frac{w_r^2}{8\delta_r} - \frac{w_r}{2}\sqrt{\frac{w_r^2}{16\delta_r^2} - \frac{1}{\delta_r}(\xi_r - \delta_r)} \tag{24}$$

$$\eta_{r\,min} = \sqrt{2}\delta_r\left[\frac{4}{w_r^2}\xi_r'^2 - 1\right] \tag{25}$$

Root Surface, Left Slope:

$$\xi_l' = -\frac{w_r^2}{8\delta_r} - \frac{w_r}{2}\sqrt{\frac{w_r^2}{16\delta_r^2} + \frac{1}{\delta_r}(\xi_l + \delta_r)} \tag{26}$$

$$\eta_{l\,min} = \sqrt{2}\delta_r\left[\frac{4}{w_r^2}\xi_l'^2 - 1\right] \tag{27}$$

Crown Surface, Right Slope:

$$\xi_r'' = -\frac{w_c^2}{8\delta_c} + \frac{w_c}{2}\sqrt{\frac{w_c}{16\delta_c^2} + \frac{1}{(\delta_c)}(\xi_r + \delta_c + t)} \tag{28}$$

$$\eta_{r\,max} = \sqrt{2}\left[t + \delta_c\left(1 - \frac{4}{w_c^2}\xi_r''^2\right)\right] \tag{29}$$

Crown Surface, Left Slope:

$$\xi_l'' = \frac{w_c^2}{8\delta_c} - \frac{w_c}{2}\sqrt{\frac{w_c}{16\delta_c^2} - \frac{1}{\delta_c}(\xi_l - \delta_c - t)} \tag{30}$$

$$\eta_{l\max} = \sqrt{2}\left[t + \delta_c\left(1 - \frac{4}{w_c^2}\xi_l^{*2}\right)\right] \tag{31}$$

It is assumed here that σ_f, the local flow stress function used in Equation 23, is defined by Equation 32. This is a more general two dimensional version (x and y) of the function used in the derivation for square welds.

$$\sigma_f = \frac{\sigma_w + \sigma_p\left[\dfrac{2x}{\left(\dfrac{w_c - w_r}{t}\right)y + w_r}\right]^{2k}}{1 + \left[\dfrac{2x}{\left(\dfrac{w_c - w_r}{t}\right)y + w_r}\right]^{2k}} \tag{32}$$

Combining Equations 23 and 32 gives the expression for σ_{fi}.

$$\sigma_{fi} = \frac{1}{t\sqrt{2}}\int_{\eta_{\min}}^{\eta_{\max}}\left\{\frac{\sigma_w + \sigma_p\left[\dfrac{2x}{\left(\dfrac{w_c - w_r}{t}\right)y + w_r}\right]^{2k}}{1 + \left[\dfrac{2x}{\left(\dfrac{w_c - w_r}{t}\right)y + w_r}\right]^{2k}}\right\}d\eta \tag{33}$$

As before, let k=1 to simplify the integration. Also, let $\left(\frac{w_c - w_r}{t}\right) = m$. Note that m is the inverse slope of the line bounding the weld zone and the parent material, so that for a uniform width weld m = 0. For right and left sloping slip lines x and y are related to ξ_r and ξ_l by Equations 34 and 35 respectively. For both sets of slip lines the relationship for η is given by Equation 36.

Right sloping slip lines: $$x = \xi_r + \eta\cos(45°) = \xi_r + \frac{\eta}{\sqrt{2}} \tag{34}$$

Left sloping slip lines: $$x = \xi_l - \eta\cos(45°) = \xi_l - \frac{\eta}{\sqrt{2}} \tag{35}$$

$$y = \eta\sin(45°) = \frac{\eta}{\sqrt{2}} \tag{36}$$

Making these substitutions into Equation 33 gives the equation to be integrated to obtain the flow initiation stress, σ_{fi}.

$$\sigma_{fi\text{-}r\,or\,l} = \frac{1}{t\sqrt{2}} \int_{\eta_{\min}}^{\eta_{\max}} \left\{ \frac{\sigma_w + \sigma_p \left[\dfrac{2\left(\xi_{r\,or\,l} \pm \dfrac{\eta}{\sqrt{2}}\right)}{\dfrac{m\eta}{\sqrt{2}} + w_r} \right]^2}{1 + \left[\dfrac{2\left(\xi_{r\,or\,l} \pm \dfrac{\eta}{\sqrt{2}}\right)}{\dfrac{m\eta}{\sqrt{2}} + w_r} \right]^2} \right\} d\eta$$

$$= \frac{1}{t\sqrt{2}} \int_{\eta_{\min}}^{\eta_{\max}} \left\{ \frac{a_2\eta^2 + a_1\eta + a_0}{b_2\eta^2 + b_1\eta + b_0} \right\} d\eta \qquad (37)$$

The polynomial coefficients in Equation 37 are defined in Table 1 for right and left sloping slip lines.

Table 1. Polynomial Coefficients in Initial Flow Stress Function

Parameter	Right Sloping Slip Lines	Left Sloping Slip Lines
m	$\left(\dfrac{w_c - w_r}{t}\right)$	$\left(\dfrac{w_c - w_r}{t}\right)$
a_0	$\sigma_w w_r^2 + 4\sigma_p \xi_r^2$	$\sigma_w w_r^2 + 4\sigma_p \xi_l^2$
a_1	$\sqrt{2}\sigma_w m w_r + 4\sqrt{2}\sigma_p \xi_r$	$\sqrt{2}\sigma_w m w_r - 4\sqrt{2}\sigma_p \xi_l$
a_2	$\sigma_w \dfrac{m^2}{2} + 2\sigma_p$	$\sigma_w \dfrac{m^2}{2} + 2\sigma_p$
b_0	$w_r^2 + 4\xi_r^2$	$w_r^2 + 4\xi_l^2$
b_1	$\sqrt{2} m w_r + 4\sqrt{2}\xi_r$	$\sqrt{2} m w_r - 4\sqrt{2}\xi_l$
b_2	$\dfrac{m^2}{2} + 2$	$\dfrac{m^2}{2} + 2$

By splitting Equation 37 into 3 separate integrals with a second order polynomial in the denominator of each integral, the following equation is obtained.

$$\sigma_{fi} = \frac{1}{\sqrt{2}}\left[a_2 I_2 + a_1 I_1 + a_0 I_0\right] \qquad (38)$$

Where:

$$I_0 = \frac{2}{\sqrt{4b_0b_2 - b_1^2}} \tan^{-1}\left[\frac{2b_2\eta + b_1}{\sqrt{4b_0b_2 - b_1^2}}\right]_{\eta_{\min}}^{\eta_{\max}}$$

$$I_1 = \left[\frac{1}{2b_2} \ln\left(b_2\eta^2 + b_1\eta + b_0\right) - \left(\frac{b_1}{2b_2} I_0 \right) \right]_{\eta_{min}}^{\eta_{max}}$$

$$I_2 = \left[\frac{\eta}{b_2} - \frac{b_1}{2b_2^2} \ln\left(b_2\eta^2 + b_1\eta + b_0\right) + \frac{\left(b_1^2 - 2b_0b_2\right)}{2b_2^2} I_0 \right]_{\eta_{min}}^{\eta_{max}}$$

If the reinforcements δ_r and δ_c are reduced to 0 in Equation 38, the initial flow stress reduces to Equation 39 with the values of m, a_i and b_i once again being defined by Table 1.

$$\sigma_{fi-r} = \left\{ \frac{a_2}{b_2} \right\} + \left\{ \frac{1}{t\sqrt{2}} \left(\frac{a_1}{2b_2} - \frac{a_2 b_1}{2b_2^2} \right) \left[\ln\left(2t^2 b_2 + \sqrt{2}tb_1 + b_0\right) - \ln\left(b_0\right) \right] \right\} +$$
$$+ \left\{ \frac{1}{t\sqrt{2}} \left(\frac{a_2\left(b_1^2 - 2b_0b_2\right)}{2b_2^2} - \frac{a_1 b_1}{2b_2} + a_0 \right) \frac{2}{\sqrt{4b_0b_2 - b_1^2}} \left[\tan^{-1} \frac{2\sqrt{2}b_2 t + b_1}{\sqrt{4b_0b_2 - b_1^2}} - \tan^{-1} \frac{b_1}{\sqrt{4b_0b_2 - b_1^2}} \right] \right\} \quad (39)$$

Equation 38 further reduces to Equations 6 and 7 if m is set to 0 and w_r and w_c are set to w.

3.3 ELONGATION AND STRAIN HARDENING

Equation 38 defines the external load at which plastic flow will begin on each of the respective slip lines. Once flow begins a linear strain hardening curve with a slope of 2α is assumed for each of the two slip lines passing through any point in the structure (Figure 6). Typically the right and left slip lines will not become active at the same applied stress level. Strain along the two slip lines after allowing for strain hardening is defined by Equations 40 through 43.

If $\sigma < \sigma_{fi\text{-}r}$: $$\varepsilon_r = 0 \quad (40)$$

If $\sigma \geq \sigma_{fi\text{-}r}$: $$\varepsilon_r = \frac{1}{2\alpha}\left(\sigma - \sigma_{fi-r}\right) \quad (41)$$

If $\sigma < \sigma_{fi\text{-}l}$: $$\varepsilon_l = 0 \quad (42)$$

If $\sigma \geq \sigma_{fi\text{-}l}$: $$\varepsilon_l = \frac{1}{2\alpha}\left(\sigma - \sigma_{fi-l}\right) \quad (43)$$

Total strain is obtained by adding the strain components due to contributions from the right and left sloping slip lines.

$$\varepsilon = \varepsilon_r + \varepsilon_l \quad (44)$$

3.4 FRACTURE STRESS AND LOCATION

For a tapered weld the assumed fracture stress function is modified from that presented in Equation 17 to allow for the variation in the y direction.

$$\sigma_{fr} = \frac{\sigma_{frw} + \sigma_{frp}\left[\dfrac{2x}{\left(\dfrac{w_c - w_r}{t}\right)y + w_r}\right]^{2n}}{1 + \left[\dfrac{2x}{\left(\dfrac{w_c - w_r}{t}\right)y + w_r}\right]^{2n}} \tag{45}$$

In Equation 45 m, w_r, w_c and k have the same definitions as used for flow stress in Equation 32. Other parameters in Equation 45 are defined as follows.

σ_{fr} = Fracture stress

σ_{frw} = Fracture stress at center of weld

σ_{frp} = Fracture stress in parent material

Once again it is assumed that the fracture will initiate at the plate surface and will propagate from that point. This fracture initiation point will be the first point at which the local stress exceeds the local fracture stress. For a tapered weld the formulation derived for Equation 18 for local stress is modified to allow for the y variation in weld width.

$$\sigma_L = \frac{\sigma_w + \sigma_p\left[\dfrac{2x}{\left(\dfrac{w_c - w_r}{t}\right)y + w_r}\right]^{2}}{1 + \left[\dfrac{2x}{\left(\dfrac{w_c - w_r}{t}\right)y + w_r}\right]^{2}} + \alpha\left[\varepsilon_r(\xi_r) + \varepsilon_l(\xi_l)\right] \tag{46}$$

Since the stresses on the root and crown surfaces on a tapered weld will not be equal as they are for a uniform width weld, it is necessary to investigate solutions at both surfaces separately to determine the location of fracture initiation.

SECTION 4. OBSERVATIONS AND RECOMMENDATIONS

The proposed model for a uniform width weld predicts yield, fracture and elongation results which are similar in form and magnitude to test results. The predicted yield stress results are higher than the observed values. This discrepancy can be partially explained by the use of $k = 1$ in the flow stress function. Use of a higher factor would result in a steeper function and would extend the region of influence of the softer weld material over a greater region resulting in a steeper fall off of the curve with increasing weld width. In the present closed form solution it is not possible to use a higher value of k. Use of $n = 1$ for the fracture stress results in a fracture initiation point outside the weld region. This is not consistent with observations, but increasing k from 1 to 2 moves the fracture initiation point to a point that is inside the weld by about 20 percent of the weld width. Other discrepancies between observed and predicted values may be attributable to the taper and reinforcement characteristics of the test samples.

Three major recommendations are proposed.

- Complete the formulation of the tapered, reinforced weld model, and compare the predicted result to observed test data.
- Develop numerical techniques to investigate the effects of higher order steepness factors for the flow stress function—i.e., set n to values greater than 1.
- Extend the model to investigate the effects of peaking and offset.

SECTION 5. REFERENCES

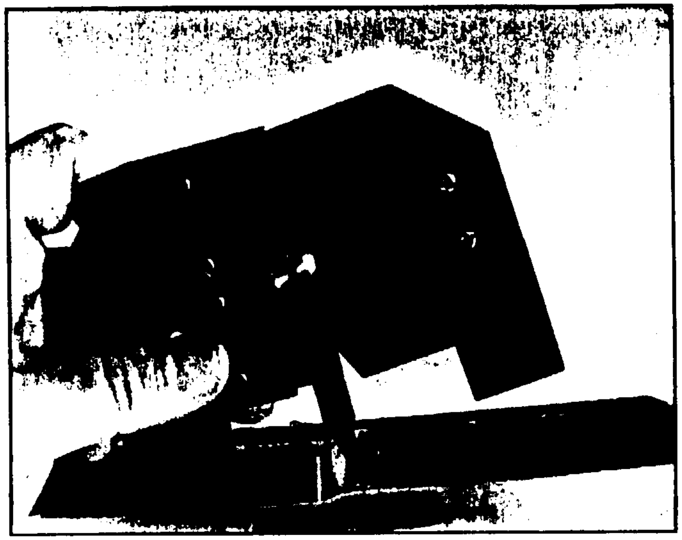
1. Rincon, C. D., Arrowood, R. and Nunes, A. C., *Plastic Flow Strain Hardening and Strength of Butt Welds in 2219-T87 Aluminum*, University of Texas at El Paso, Submitted to Welding Journal, August, 1994.

2. Beil, R. J., Hahn, G. T., Rubin, C., Colletti, M. A. and McClearen, V. B., *Effects of Microstructure on the Strength and Toughness of Welds*, School of Engineering, Vanderbilt University, November 1987.

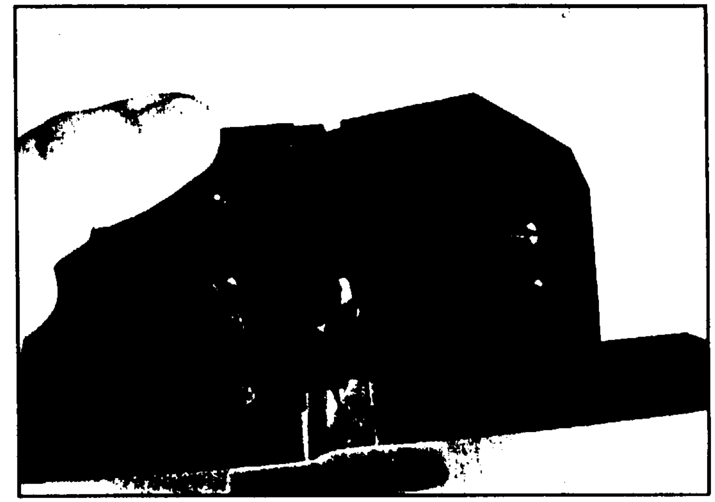
3. Nunes, A. C., Novak, H. L., McIlwain, M. C., *Weld Geometry Strength Effect in 2219-T87 Aluminum*, NASA Technical Memorandum, NASA-TM-82404, March 1991.

Appendix II

OPERATING INSTRUCTIONS
NRC MISMATCH AND PEAKING MEASUREMENT GAUGE

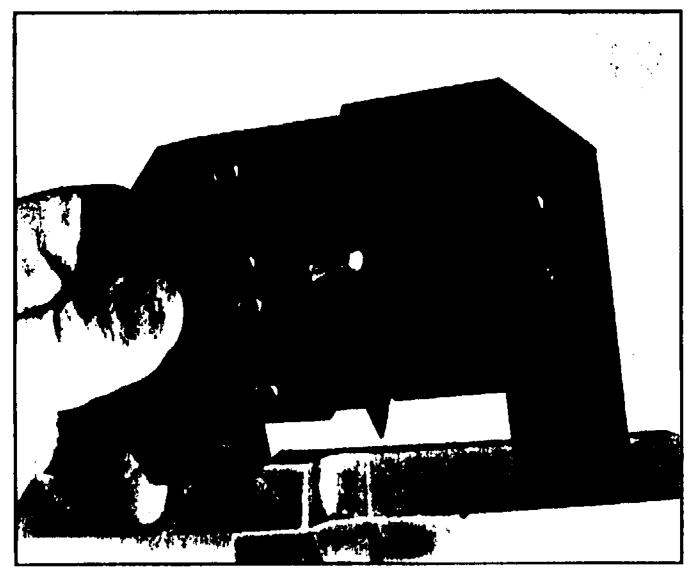


STEP 1.
Extend the centerline pointer and place its tip on the center of the weld.

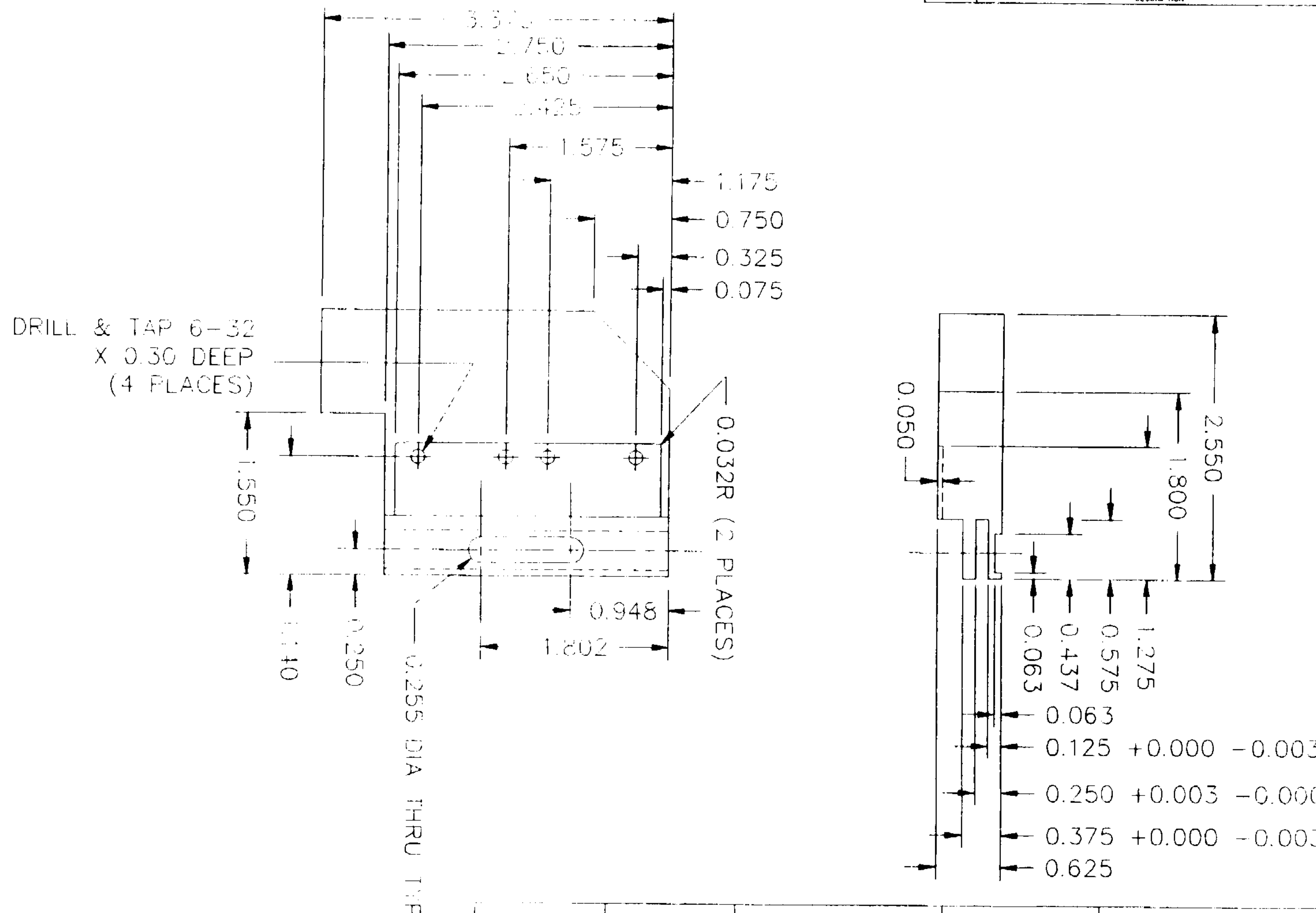


STEP 2.
Push down on the left half so that its base is flat against the workpiece.
Keep the centerline pointer tip centered on the weld.

STEP 3.
Hold the left half firmly against the workpiece so that it does not move.
Push down on the right half so that its base is flat against the workpiece.
Keep the centerline pointer tip centered on the weld.



STEP 4.
Read the mismatch and peaking measurements from the scales on the gauge.
Measurements are relative to the parent metal surface left of the weld.
NOTE: If the gauge moves when pulled away from the workpiece, tighten the nut on the back of the gauge and repeat steps 1 through 4.



NOTES:
1. DEBURR ALL HOLES AND SHARP EDGES

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .01 .XXX ± .005 ANGLES ± 1°

MATERIAL 7075 ALUMINUM

FINISH

DO NOT SCALE DRAWING

NEXT ASSY | USED ON

APPLICATION

CONTRACT NO

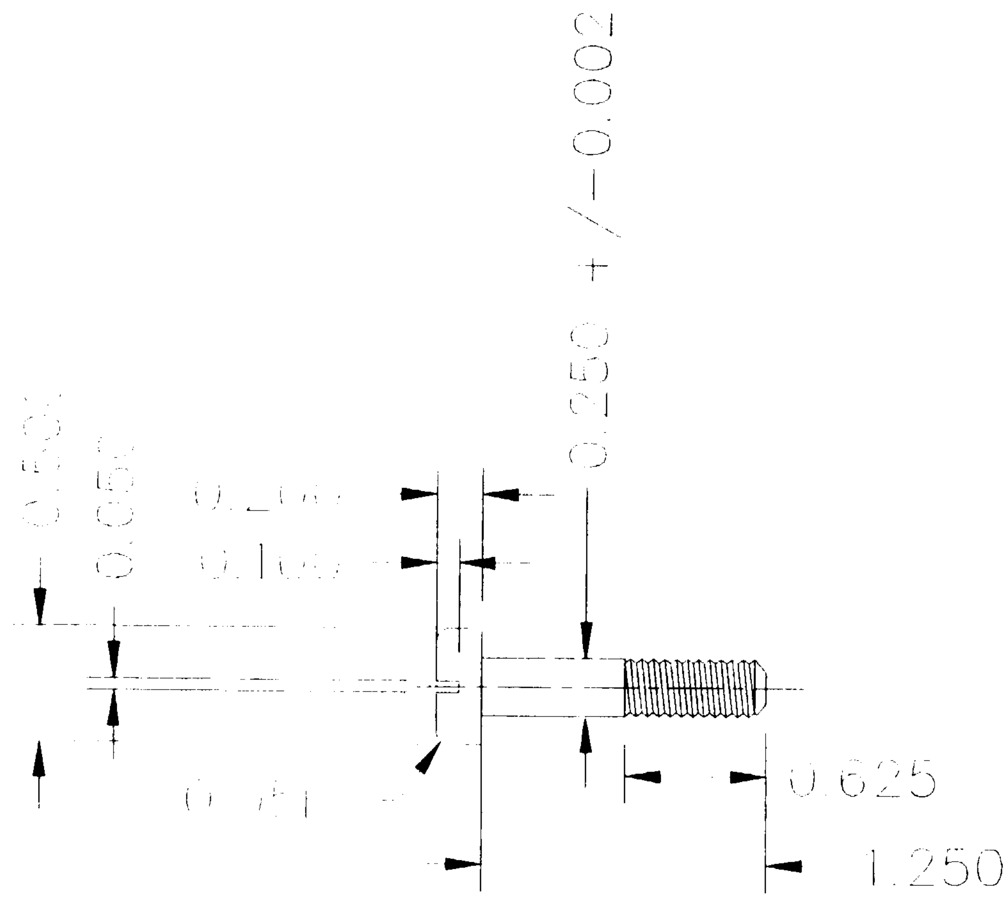
APPROVALS	DATE
DRAWN S. GORDON	11/24/93
CHECKED	
ISSUED	

NICHOLS RESEARCH CORP
P.O. BOX 400002 - 1502 HUNTSVILLE, AL 35802 - 1326

MISMATCH & PEAKING GAUGE, LEFT HALF

SIZE B | FSCM NO. | DWG NO

SCALE | FILE: LEFTHALF.DWG | SHEET 1 - 1



DON'T FORGET CENTER LINE POINTER (SIGHTS)/WHATEVER
AND SCALE MOUNTING HOLES

NOTES:
1. DEBURR ALL HOLES AND SHARP EDGES.

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE
FRACTIONS DECIMALS ANGLES

MATERIAL 7075 ALUMINUM

FINISH

DO NOT SCALE DRAWING

NEXT ASSY USED ON
APPLICATION

CONTRACT NO.

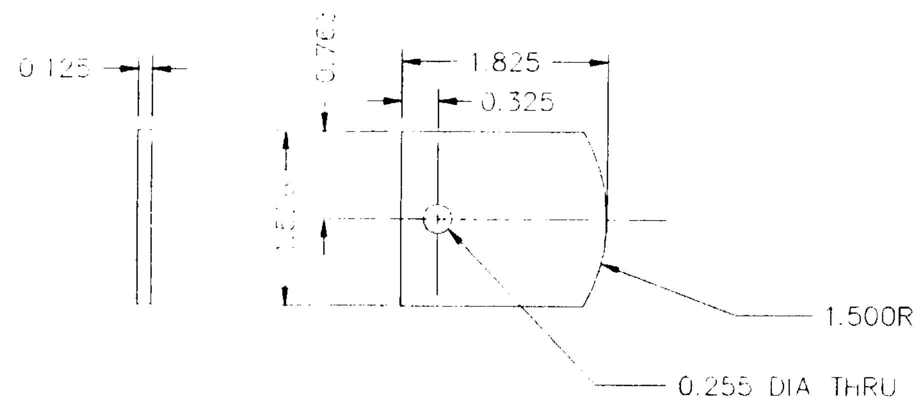
APPROVALS	DATE
DRAWN S. GORDON	11/24/93
CHECKED	
ISSUED	

NICHOLS RESEARCH CORP
P.O. BOX 400002 - 1502 HUNTSVILLE, AL 35802 - 1226

MISMATCH & PEAKING GAUGE,
PIVOT BOLT

SIZE B | FSCM NO. | DWG NO.

SCALE | FILE PIVOT.DWG | SHEET



NOTES:
1. DEBURR ALL HOLES AND SHARP EDGES

REV	DESCRIPTION	DATE	APPROVED

REVISIONS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE
FRACTIONS ± DECIMALS .XX ± .01 .XXX ± .005 ANGLES ± 1°

MATERIAL 7075 ALUMINUM

FINISH

DO NOT SCALE DRAWING

NEXT ASSY | USED ON

APPLICATION

CONTRACT NO.

APPROVALS	DATE
DRAWN S. GORDON	11/24/93
CHECKED	
ISSUED	

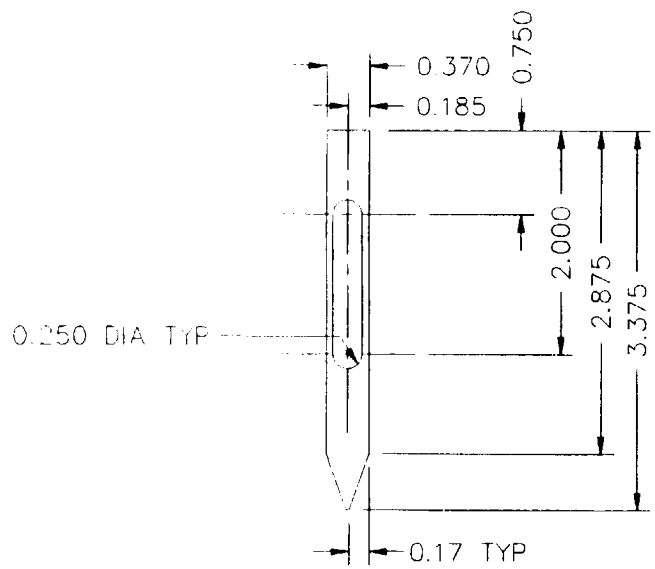
NICHOLS RESEARCH CORP
P.O. BOX 400002 - 1502 HUNTSVILLE, AL 35802 1326

MISMATCH & PEAKING GAUGE,
PEAKING SCALE PLATE

SIZE B | FSCM NO. | DWG. NO.

SCALE | FILE: PEAKPLAT.DWG | SHEET 1 - 1

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED



NOTES:
1. DEBURR ALL HOLES AND SHARP EDGES

NEXT ASSY | USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE
FRACTIONS ± — DECIMALS .XX ± .01 .XXX ± .005 ANGLES ± 1°

MATERIAL STAINLESS STEEL 0.063" THICK

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN S. GORDON	01/07/94
CHECKED	
ISSUED	

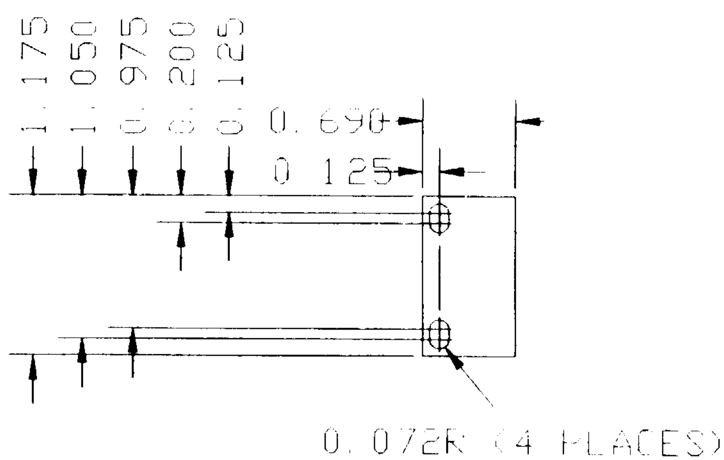
NICHOLS RESEARCH CORP
P.O. BOX 400002 - 1502 HUNTSVILLE, AL. 35802 - 1326

MISMATCH & PEAKING GAUGE, POINTER

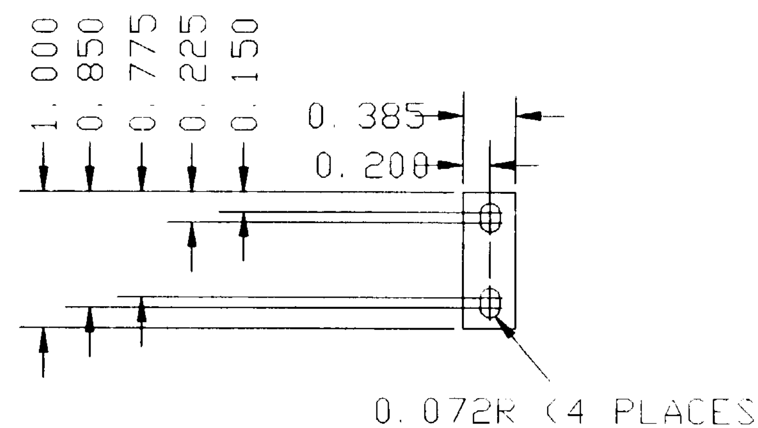
SIZE B | FSCM NO. | DWG NO.

SCALE | FILE: POINTER.DWG | SHEET 1 - 1

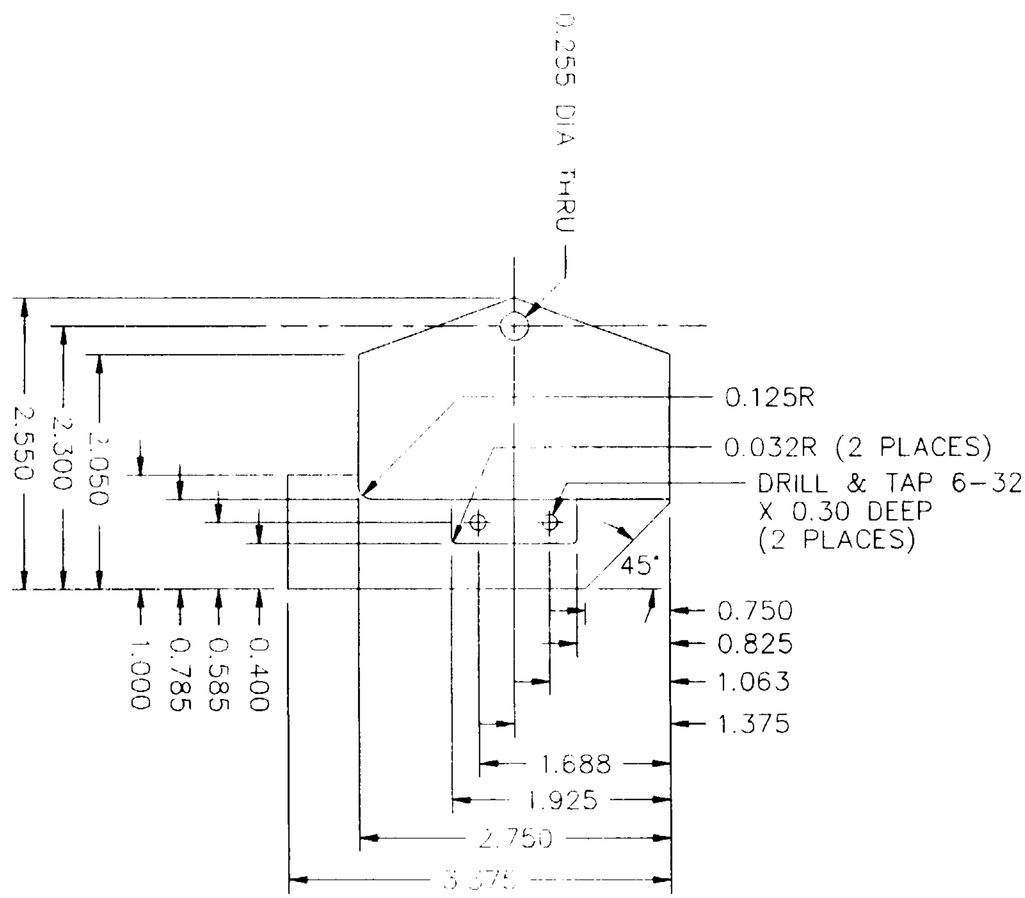
SCALE PLATE
2 REQUIRED

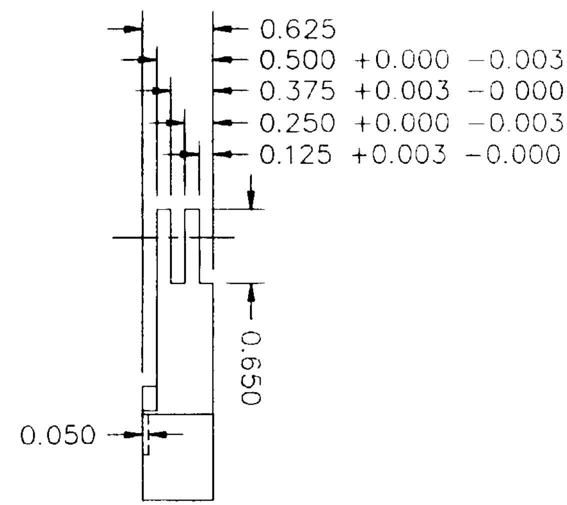


MARK PLATE
1 REQUIRED



MATERIAL: 0.060" THICK ALUMINUM 6061





NOTES:
1 DEBURR ALL HOLES AND SHARP EDGES

REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS ± — DECIMALS .XX ± .01 .XXX ± .005 ANGLES ± 1°

MATERIAL 7075 ALUMINUM

FINISH

DO NOT SCALE DRAWING

NEXT ASSY | USED ON
APPLICATION

CONTRACT NO.

APPROVALS	DATE
DRAWN S. GORDON	11/24/93
CHECKED	
ISSUED	

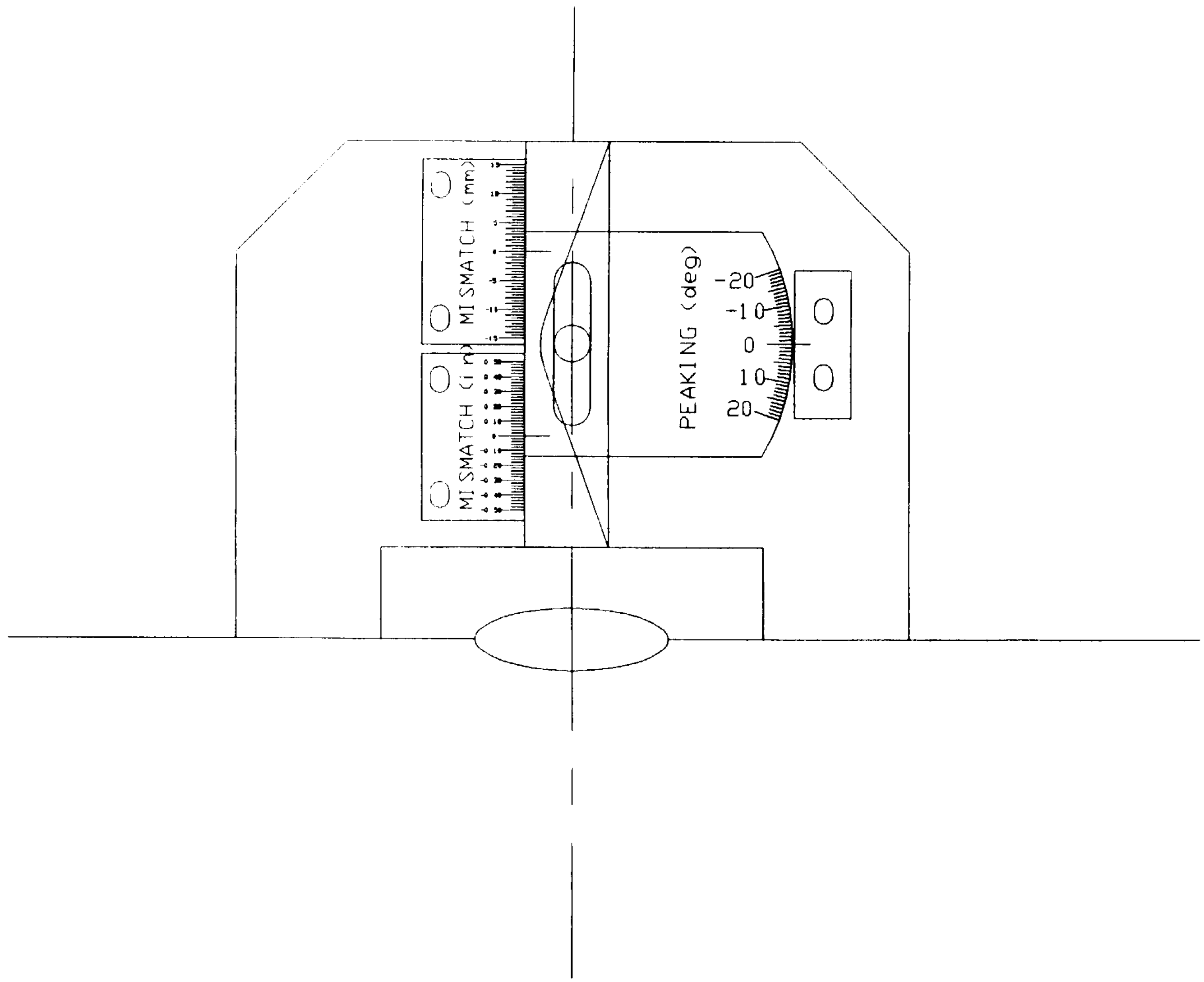
NICHOLS RESEARCH CORP
P.O. BOX 400002 – 1502 HUNTSVILLE, AL. 35802 – 1326

MISMATCH & PEAKING GAUGE, RIGHT HALF

SIZE B | FSCM NO. | DWG. NO.

SCALE | FILE: RTHALF.DWG | SHEET 1 – 1

REQUIREMENTS: Peaking +/- 20 degs; Mismatch +/- 0.25"
Must work for reinforcement of +/- 0.25"



Appendix III

APPENDIX III

Weld Model Test and Analysis Data AL2219

Calibration Panels:
Material (AL2219) and Panel Thickness (0.250")

Panel 8 @ 6 IPM - 170A, 210A, 220A, 230A, 240A and 250A
Panel 9 @ 9 IPM - 170A, 180A, 190A, 200A, 210A and 220A
Panel 10 @ 12 IPM - 140A, 150A, 160A, 170A, 180A and 190A

The 6 Controller Parameters for 0.25" AL2219: E0, E1, E2, A0, A1, A2

[Efficiency = E0 +(E1 * Pg)+(E2 *(Travel Speed))]
[Alpha (Distribution) = A0 +(A1 * Pg)+(A2 * Pd)]

Efficiency = .386 +(-5.36e-5 (Pg - 3867))+(.011 (velocity - 9.5))
E0 = 0.3861761
E1 = -5.3554e-05
E2 = 0.01104974

Distribution (Alpha) = 0.124 +(-4.76e-5 * Pg)+(-1.04e-4 * Pd)
A0 = 0.1240582
A1 = -4.758603e-05
A2 = -0.0001035274

Width Residuals:
Using 7 Control Parameters (3 Efficiency parameters and 4 Distribution parameters) for material (AL2219) and panel thickness (0.250")

Panel segment, Crown Measured[inches], Crown Predicted[inches], Crown Error[predicted-measured], Root Measured[inches], Root Predicted[inches], Root Error[predicted-measured], C-current[amperes], V-voltage[volts], S-fixture speed(velocity)[IPM]

Panel Ref #	Crown Meas.	Crown Pred.	Crown Error	Root Meas.	Root Pred.	Root Error	C Meas.	V Meas.	S Meas.
81	0.369	0.425	0.056	0.116	0.062	-0.054	141.69	18.82	6.04
82	0.371	0.395	0.024	0.185	0.17	-0.015	150.53	19.24	6.04
83	0.373	0.371	-0.002	0.235	0.243	0.008	160.28	19.35	5.99
84	0.381	0.359	-0.022	0.288	0.317	0.029	170.09	19.81	6.03
85	0.385	0.34	-0.045	0.316	0.338	0.022	180.09	20.37	5.99
86	0.398	0.351	-0.047	0.382	0.441	0.059	189.65	20.87	6.02
91	0.344	0.346	0.002	0.232	0.245	0.013	171.31	20.21	9.00
92	0.359	0.357	-0.002	0.242	0.241	-0.001	181.14	20.60	8.98
93	0.362	0.349	-0.013	0.271	0.276	0.005	191.27	21.03	9.04
94	0.371	0.358	-0.013	0.286	0.285	-0.001	201.01	21.42	9.02
95	0.382	0.376	-0.006	0.307	0.303	-0.004	211.04	22.30	9.04
96	0.405	0.424	0.019	0.329	0.334	0.005	220.94	22.46	9.05
101	0.298	0.301	0.003	0.195	0.21	0.015	171.21	19.34	12.01
102	0.335	0.317	-0.018	0.252	0.244	-0.008	211.32	20.99	11.99
103	0.353	0.358	0.005	0.265	0.252	-0.013	221.05	21.52	11.99
104	0.359	0.359	0.000	0.281	0.273	-0.008	231.33	21.72	12.05
105	0.364	0.373	0.009	0.290	0.278	-0.012	241.04	22.16	11.99
106	0.384	0.421	0.037	0.309	0.305	-0.004	251.32	22.62	11.99

RMS = Square Root{(Sum[(Error)squared]/n)}

Crown Width RMS = 0.024867"
Root Width RMS = 0.022293"
both Crown and Root = 0.023615"

Calibration Panels:
Voltage Residuals: Material (AL2219) and Panel Thickness (0.250")

V-voltage Measured[volts], V-voltage Predicted[volts],
V-voltage Error[volts],Crown Width[inches],Root Width[inches],
C-current[Amperes],S-fixture speed[Inches Per Minute]

Panel Ref #	V Meas.	V Pred.	V Error	Crown Meas.	Root Meas.	C Meas.	S Meas.
81	18.82	18.97	0.15	0.369	0.116	141.69	6.04
82	19.24	19.33	0.09	0.371	0.185	150.53	6.04
83	19.35	19.64	0.29	0.373	0.235	160.28	5.99
84	19.81	20.04	0.23	0.381	0.288	170.09	6.03
85	20.37	20.50	0.13	0.385	0.316	180.09	5.99
86	20.87	20.94	0.07	0.398	0.382	189.65	6.02
91	20.21	19.89	-0.32	0.344	0.232	171.31	9.00
92	20.60	20.30	-0.30	0.359	0.242	181.14	8.98
93	21.03	20.74	-0.29	0.362	0.271	191.27	9.04
94	21.42	21.17	-0.25	0.371	0.286	201.01	9.02
95	22.30	21.79	-0.51	0.382	0.307	211.04	9.04
96	22.46	22.17	-0.29	0.405	0.329	220.94	9.05
101	19.34	19.35	0.01	0.298	0.195	171.21	12.01
102	20.99	21.07	0.08	0.335	0.252	211.32	11.99
103	21.52	21.56	0.04	0.353	0.265	221.05	11.99
104	21.72	21.95	0.23	0.359	0.281	231.33	12.05
105	22.16	22.44	0.28	0.364	0.290	241.04	11.99
106	22.62	22.96	0.34	0.384	0.309	251.32	11.99

Voltage RMS error = 0.250671V

Test Panel:
When using the empirical weld model to generate weld schedules giving specific weld geometry (root and crown widths), weld voltage must be calculated in order to determine the commanded weld current component of the weld schedule to provide the required power generated needed to achieve the desired root and crown widths.

Voltage = B0 + (B1 * Pg) + (B2 * Speed)

The three voltage terms B0, B1 and B2 are derived empirically from the three calibration runs.

Voltage = 15.29 + 0.001498 * Pg + -0.0996 * velocity

B0 = 15.29
B1 = 0.001498
B2 = -0.0996

Pg = power generated,
Pd = Pg * efficiency = Power delivered

From the weld model parameters derived from the set of calibration panels, a weld schedule was generated from the weld model to produce a weld with specific weld geometry (Crown and Root widths). All AL2219 welds were performed with the torch height held constant at 4mm.

Test Panel:
Material(AL2219) and Panel Thickness (0.250")

Panel Ref #	C Command Amps	S Command IPM	Voltage Predicted	Crown Width Predicted	Root Width Predicted.
T121	180A	8	20.2	.374	.249
T122	155A	4.9	19.4	.391	.269
T123	165A	4.9	19.8	.391	.339
T124	240A	15	22.0	.325	.296
T125	230A	7.9	22.4	.382	.366

Test Panel:
Width Residuals: Material (AL2219) and Panel Thickness (0.250")

Panel Ref #	Crown Pred.	Crown Meas.	Crown Error	Root Pred.	Root Meas.	Root Error	C Meas.	V Meas.	S Meas.
T121	.376	.365	-0009	.254	.272	0.021	181.16	20.23	7.98
T122	.376	.378	-0.034	.214	.284	0.036	156.56	19.40	4.89
T123	.397	.386	-0.054	.233	.301	0.023	164.71	19.76	4.90
T124	.342	.345	0.002	.285	.272	-0.05	241.23	21.99	15.01
T125	.399	.404	0.009	.349	.375	0.023	231.27	22.36	7.91

Crown Width RMS = 0.02930"
Root Width RMS = 0.023760"
both Crown and Root = 0.026690"

Test Panel:
Voltage Residuals: Material (AL2219) and Panel Thickness (0.250")

Panel Ref #	V Pred.	V Meas.	V Error	Crown Pred.	Crown Meas.	Root Pred.	Root Meas.	C Meas.	S Meas.
T121	20.2	20.23	0.03	.376	.365	.254	.272	181.16	7.98
T122	19.4	19.40	0.00	.376	.378	.214	.284	156.56	4.89
T123	19.8	19.76	-0.04	.397	.386	.233	.301	164.71	4.90
T124	22.0	21.99	-0.01	.342	.345	.285	.272	241.23	15.01
T125	22.4	22.36	-0.04	.399	.404	.349	.375	231.27	7.91

Weld Voltage RMS = 0.28983V

Width error between controller calculated crown and root widths and actual measurements of crown and root widths.

Calibration Panels:
Crown Width RMS Error: 0.024867"
Root Width RMS Error: 0.022293"
Both(Average)RMS Error: 0.023615"

Test Panel:
Crown Width RMS Error: 0.02930"
Root Width RMS Error: 0.023760"
Both(Average)RMS Error: 0.026690"

The 7 Controller Parameters for 0.25" AL2219 With New Alpha Term (A3) [power * power / speed]: E0, E1, E2, A0, A1, A2, A3

Efficiency = E0 +(E1 * Pg)+(E2 *(Travel Speed))
Alpha (Distribution) = A0 +(A1 * Pg)+(A2 * Pd)+(A3 *(Pg * Pg))

Efficiency = .386 + (-5.36e-5 *(Pg - 3867)) + (.011 *(velocity - 9.5))

E0 = 0.3861761
E1 = -5.3554e-05
E2 = 0.01104974

Alpha = 0.59 +(2.10e-4 * Pg)+(-6.91e-4 * Pd)+(-7.41e-9 (Pg * Pg))

A0 = 0.5916516
A1 = 0.0002103581
A2 = -0.0006907139
A3 = -7.413905e-09

Calibration Panels:
Width Residuals: Using 7 Control Parameters (3 Efficiency parameters and 4 Distribution parameters) for 0.250' AL2219.

Panel segment, Crown Measured[inches], Crown Predicted[inches], Crown Error[predicted-measured], Root Measured[inches], Root Predicted[inches], Root Error[predicted-measured], C-current[amperes], V-voltage[volts], S-fixture speed(velocity)[IPM]

Panel Ref #	Crown Meas.	Crown Pred.	Crown Error	Root Meas.	Root Pred.	Root Error	C Meas.	V Meas.	S Meas.
81	0.369	0.386	0.017	0.116	0.093	-0.023	141.69	18.82	6.04
82	0.371	0.372	0.001	0.185	0.181	-0.004	150.53	19.24	6.04
83	0.373	0.364	-0.009	0.235	0.249	0.014	160.28	19.35	5.99
84	0.381	0.371	-0.010	0.288	0.306	0.018	170.09	19.81	6.03
85	0.385	0.377	-0.008	0.316	0.303	-0.013	180.09	20.37	5.99
86	0.398	0.407	0.009	0.382	0.386	0.004	189.65	20.87	6.02
91	0.344	0.340	-0.004	0.232	0.251	0.019	171.31	20.21	9.00
92	0.359	0.357	-0.002	0.242	0.242	-0.000	181.14	20.60	8.98
93	0.362	0.352	-0.010	0.271	0.273	0.002	191.27	21.03	9.04
94	0.371	0.362	-0.009	0.286	0.281	-0.005	201.01	21.42	9.02
95	0.382	0.377	-0.005	0.307	0.301	-0.006	211.04	22.30	9.04
96	0.405	0.421	0.016	0.329	0.337	0.008	220.94	22.46	9.05
101	0.298	0.309	0.011	0.195	0.202	0.007	171.21	19.34	12.01
102	0.335	0.330	-0.005	0.252	0.231	-0.021	211.32	20.99	11.99
103	0.353	0.355	0.002	0.265	0.245	-0.020	221.05	21.52	11.99
104	0.359	0.359	0.000	0.281	0.273	-0.008	231.33	21.72	12.05
105	0.364	0.359	-0.005	0.290	0.291	0.001	241.04	22.16	11.99
106	0.384	0.391	0.007	0.309	0.337	0.028	251.32	22.62	11.99

RMS = Square Root{(Sum[(Error)squared]/n)}

Crown Width RMS = 0.008597"
Root Width RMS = 0.013888"
both Crown and Root = 0.011549"

Calibration Panels:
Voltage Residuals: Using 7 Control Parameters (3 Efficiency parameters and 4 Distribution parameters) for 0.250' AL2219.

V-voltage Measured[volts], V-voltage Predicted[volts],
V-voltage Error[volts],Crown Width[inches],Root Width[inches],
C-current[Amperes],S-fixture speed[Inches Per Minute]

Panel Ref #	V Meas.	V Pred.	V Error	Crown Meas.	Root Meas.	C Meas.	S Meas.
81	18.82	18.97	0.15	0.369	0.116	141.69	6.04
82	19.24	19.33	0.09	0.371	0.185	150.53	6.04
83	19.35	19.64	0.29	0.373	0.235	160.28	5.99
84	19.81	20.04	0.23	0.381	0.288	170.09	6.03
85	20.37	20.50	0.13	0.385	0.316	180.09	5.99
86	20.87	20.94	0.07	0.398	0.382	189.65	6.02
91	20.21	19.89	-0.32	0.344	0.232	171.31	9.00
92	20.60	20.30	-0.30	0.359	0.242	181.14	8.98
93	21.03	20.74	-0.29	0.362	0.271	191.27	9.04
94	21.42	21.17	-0.25	0.371	0.286	201.01	9.02
95	22.30	21.79	-0.51	0.382	0.307	211.04	9.04
96	22.46	22.17	-0.29	0.405	0.329	220.94	9.05
101	19.34	19.35	0.01	0.298	0.195	171.21	12.01
102	20.99	21.07	0.08	0.335	0.252	211.32	11.99
103	21.52	21.56	0.04	0.353	0.265	221.05	11.99
104	21.72	21.95	0.23	0.359	0.281	231.33	12.05
105	22.16	22.44	0.28	0.364	0.290	241.04	11.99
106	22.62	22.96	0.34	0.384	0.309	251.32	11.99

Voltage RMS error = 0.250671V

Test Panel:
When using the empirical weld model to generate weld schedules giving specific weld geometry (root and crown widths), weld voltage must be calculated in order to determine the commanded weld current component of the weld schedule to provide the required power generated needed to achieve the desired root and crown widths.

Voltage = B0 + (B1 * Pg) + (B2 * Speed)

The three voltage terms B0, B1 and B2 are derived empirically from the three calibration runs.

Voltage = 15.29 + 0.001498 * Pg + -0.0996 * velocity

B0 = 15.29
B1 = 0.001498
B2 = -0.0996

Pg = power generated,
Pd = Pg * efficiency = Power delivered

From the weld model parameters derived from the set of calibration panels, a weld schedule was generated from the weld model to produce a weld with specific weld geometry (Crown and Root widths). All AL2219 welds were performed with the torch height held constant at 4mm.

Test Panel:
Using 7 Control Parameters (3 Efficiency parameters and 4 Distribution parameters) for material (AL2219) and panel thickness (0.250")

Panel Ref #	C Command Amps	S Command IPM	Voltage Predicted	Crown Width Predicted	Root Width Predicted.
T121	180A	8	20.2	.374	.249
T122	155A	4.9	19.4	.391	.269
T123	165A	4.9	19.8	.391	.339
T124	240A	15	22.0	.325	.296
T125	230A	7.9	22.4	.382	.366

Test Panel:
Using 7 Control Parameters (3 Efficiency parameters and 4 Distribution parameters) for 0.250' AL2219.

Panel Ref #	Crown Pred.	Crown Meas.	Crown Error	Root Pred.	Root Meas.	Root Error	C Meas.	V Meas.	S Meas.
T121	.374	.365	-0009	.249	.272	0.023	181.16	20.23	7.98
T122	.391	.378	-0.013	.269	.284	0.015	156.56	19.40	4.89
T123	.391	.386	-0.005	.339	.301	-0.038	164.71	19.76	4.90
T124	.325	.345	0.020	.296	.272	-0.024	241.23	21.99	15.01
T125	.382	.404	0.022	.366	.375	0.009	231.27	22.36	7.91

Crown Width RMS = 0.015111"
Root Width RMS = 0.019498"
both Crown and Root = 0.017443"

Test Panel:
Voltage Residuals: Using 7 Control Parameters (3 Efficiency parameters and 4 Distribution parameters) for 0.250' AL2219.

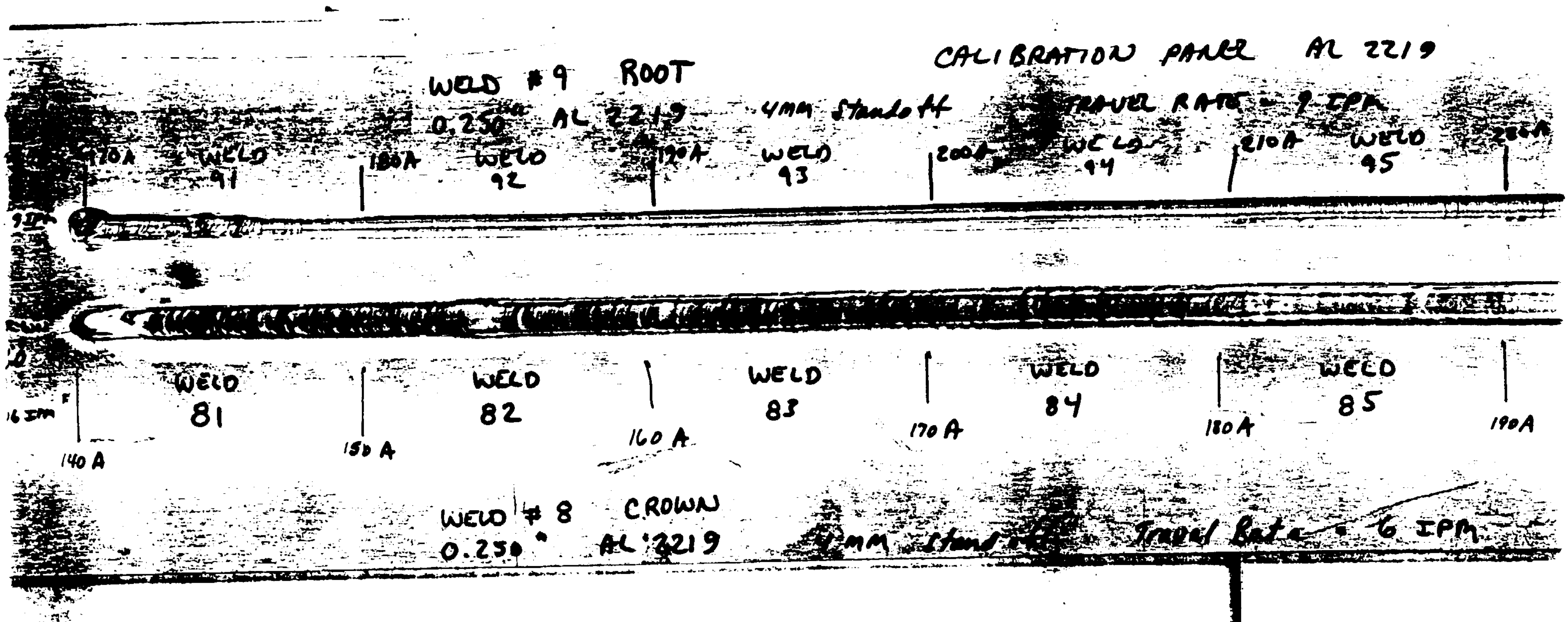
Panel Ref #	V Pred.	V Meas.	V Error	Crown Pred.	Crown Meas.	Root Pred.	Root Meas.	C Meas.	S Meas.
T121	20.2	20.23	0.03	.374	.365	.249	.272	181.16	7.98
T122	19.4	19.40	0.00	.391	.378	.269	.284	156.56	4.89
T123	19.8	19.76	-0.04	.391	.386	.339	.301	164.71	4.90
T124	22.0	21.99	-0.01	.325	.345	.296	.272	241.23	15.01
T125	22.4	22.36	-0.04	.382	.404	.366	.375	231.27	7.91

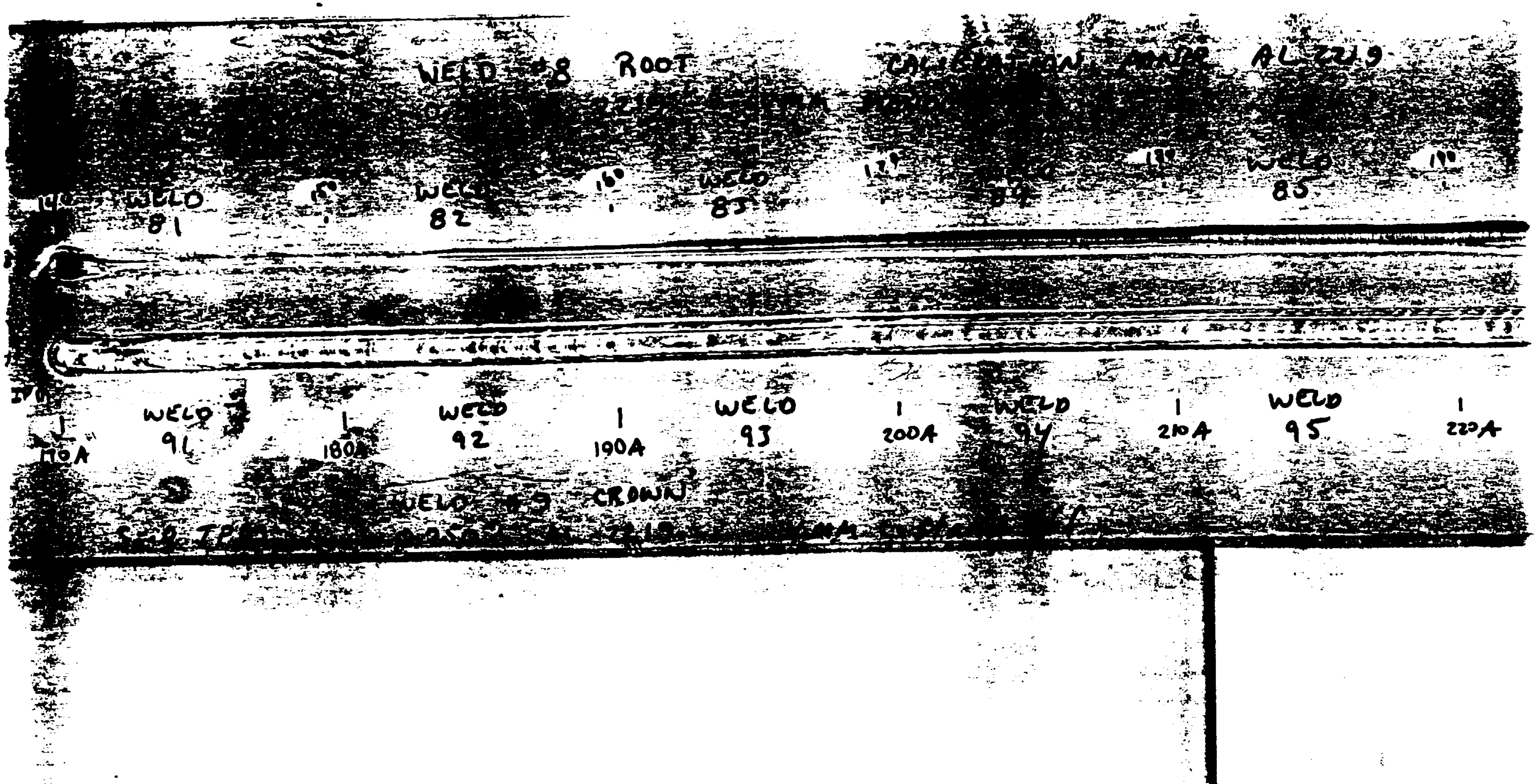
Weld Voltage RMS = 0.28983V

Error between controller calculated crown and root widths and actual measurements of crown and root widths.

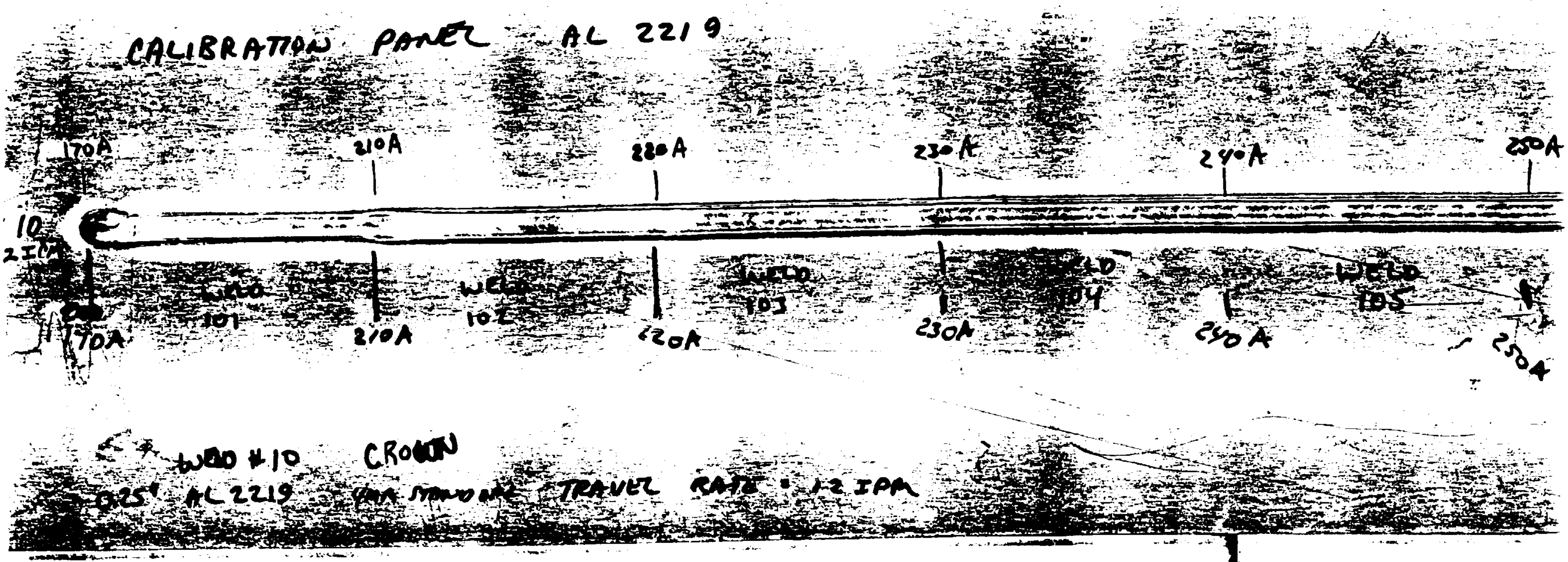
Error Calibration Panels:
Crown Width RMS Error: 0.008597"
Root Width RMS Error: 0.013888"
Both(Average)RMS Error: 0.011549"

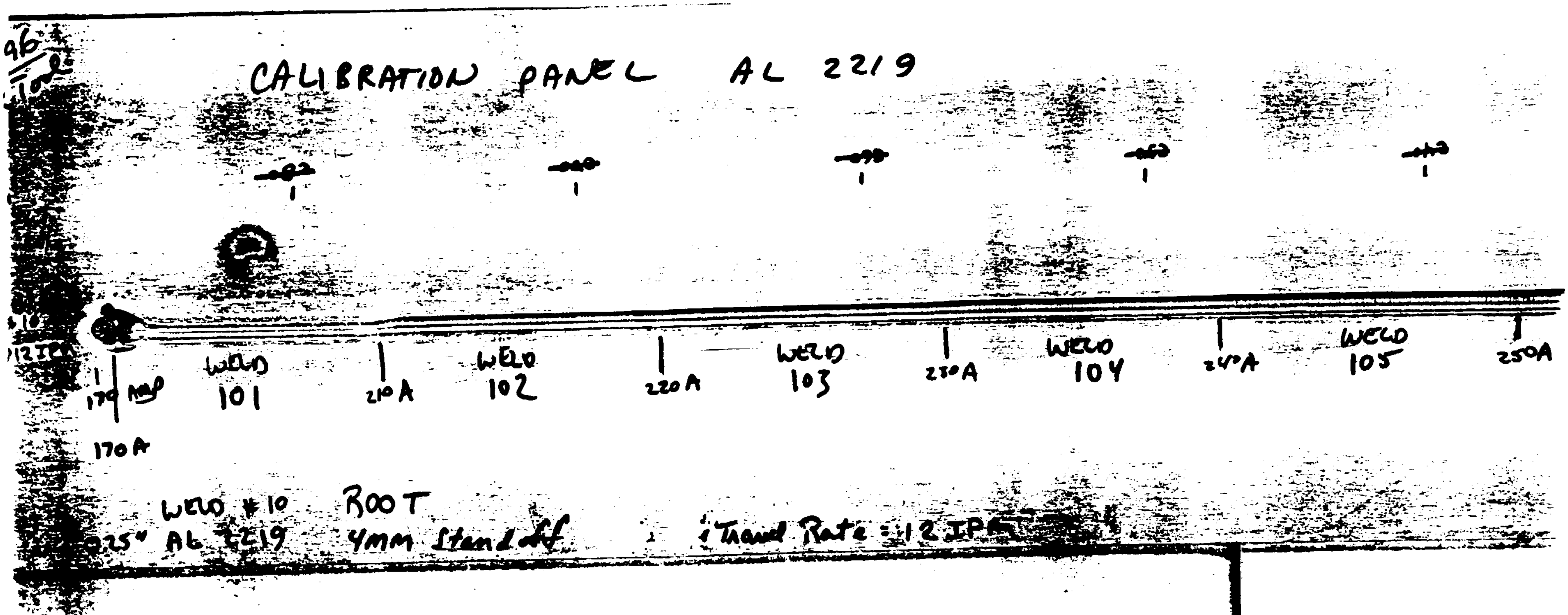
Error Test Panel:
Crown Width RMS Error: 0.015111"
Root Width RMS Error: 0.019498"
Both(Average)RMS Error: 0.017443"


CALIBRATION PANEL AL 2219
WELD #9 ROOT
0.250 AL 2219
4MM Standoff
TRAVEL RATE = 9 IPM
170A
WELD 91
180A
WELD 92
190A
WELD 93
200A
WELD 94
210A
WELD 95
220A
WELD 81
WELD 82
WELD 83
WELD 84
WELD 85
140 A
150 A
160 A
170 A
180 A
190 A
WELD #8 CROWN
0.250" AL 2219
4MM Standoff
Travel Rate = 6 IPM

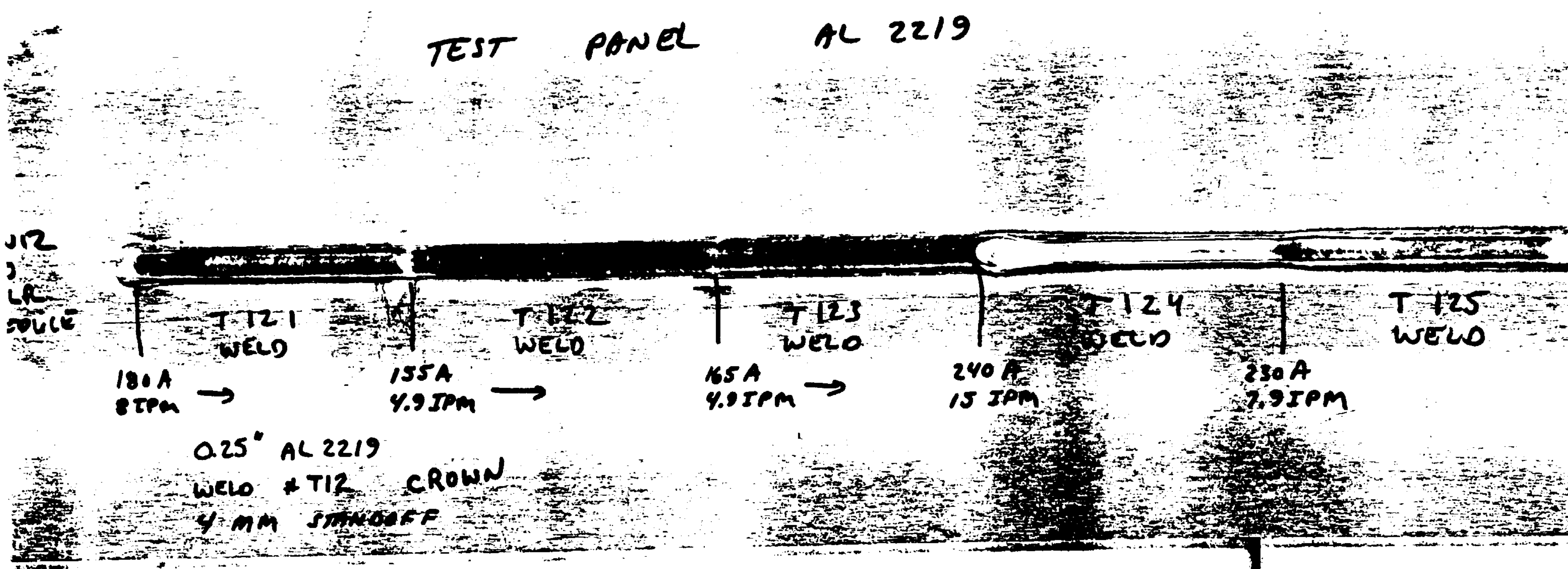


WELD #8 ROOT
AL 2219
WELD 81
WELD 82
WELD 83
WELD 85
WELD 91
WELD 92
WELD 93
WELD 94
WELD 95
170A
180A
190A
200A
210A
220A
CROWN

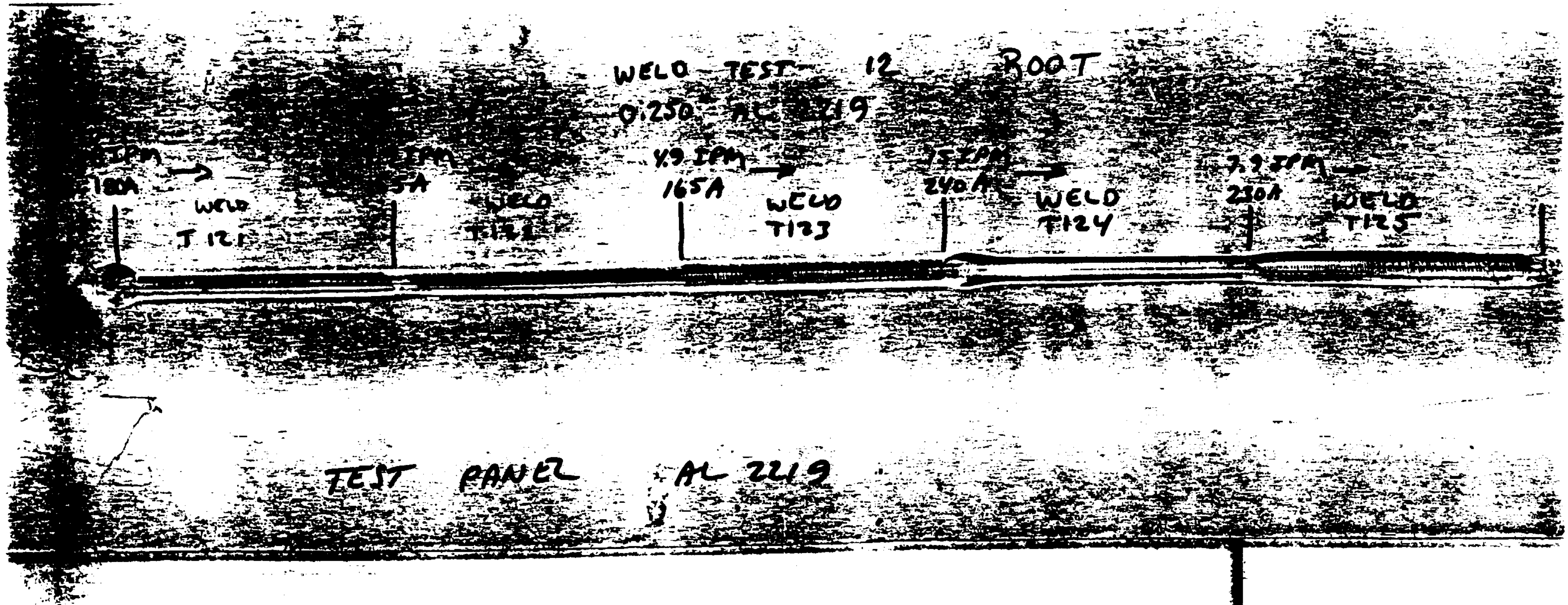

CALIBRATION PANEL AL 2219
170A
210A
220A
230A
240A
250A
10
2IPM
WELD 101
WELD 102
WELD 103
WELD 104
WELD 105
170A
210A
220A
230A
240A
250A
WELD #10 CROWN
AL 2219
TRAVEL RATE = 12 IPM



CALIBRATION PANEL AL 2219
WELD 101
WELD 102
WELD 103
WELD 104
WELD 105
170A
210A
220A
230A
240A
250A
WELD # 10 ROOT
.025" AL 2219 4mm Standoff
Travel Rate = 12 IPM



TEST PANEL AL 2219
T121 WELD
T122 WELD
T123 WELD
T124 WELD
T125 WELD
180A 8IPM →
155A 4.9IPM →
165A 4.9IPM →
240A 15 IPM
230A 7.9IPM
0.25" AL 2219
WELD #T12 CROWN
4 MM STANDOFF



WELD TEST 12 ROOT
0.250" AL 2219
180A
WELD
T121
WELD
T122
4.9 IPM
165A
WELD
T123
240A
WELD
T124
7.9 IPM
230A
WELD
T125
TEST PANEL AL 2219

Appendix IV

APPENDIX IV

Weld Model Test and Analysis Data AL2195

Calibration Panels:
Material(AL2195) and Panel Thickness (0.200")

Panel W2 @ 17 IPM - 120A, 130A, 140A, 150A and 160A
Panel W3 @ 7 IPM - 80A, 90A, 100A, 110A and 120A
Panel W4 @ 12 IPM - 110A, 120A, 130A, 140A and 150A

The 6 Controller Parameters for 0.20" AL2195: E0, E1, E2, A0, A1, A2

[Efficiency = E0 + E1 * Pg + E2 * (Travel Speed)]
[Distribution (Alpha)= A0 + A1 * Pg + A2 * Pd + A3 (Pg * Pg)]

Efficiency = .342 + -7.05e-5 (Pg - 3867) + .024 (velocity - 9.5)
E0 = 0.342 + (-7.05e-5 * -3867) + (0.24 * -9.5)
E1 = -7.05e-5
E2 = 0.024

Distribution (Alpha)= 0.11 + -9.09e-5 Pg + 1.66e-4 Pd
A0 = 0.11
A1 = -9.09e-5
A2 = 1.66e-4

Calibration Panels:
Width Residuals: Material(AL2195) and Panel Thickness (0.200")

Panel segment, Crown Measured[inches], Crown Predicted[inches], Crown Error[predicted-measured], Root Measured[inches], Root Predicted[inches], Root Error[predicted-measured], C-current[amperes], V-voltage[volts], S-fixture speed(velocity)[IPM]

Panel Ref #	Crown Meas.	Crown Pred.	Crown Error	Root Meas.	Root Pred.	Root Error	C Meas.	V Meas.	S Meas.
W21	0.335	0.352	0.017	0.350	0.354	0.004	129.00	25.45	7.01
W22	0.269	0.278	0.009	0.222	0.240	0.018	118.83	23.02	17.11
W23	0.275	0.280	0.005	0.230	0.241	0.011	129.61	23.33	17.03
W24	0.280	0.282	0.002	0.225	0.218	-0.007	140.20	23.59	17.00
W25	0.285	0.286	0.001	0.237	0.229	-0.008	151.04	24.14	16.98
W26	0.300	0.312	0.012	0.252	0.247	-0.005	161.13	24.67	17.00
W31	0.290	0.286	-0.004	0.253	0.248	-0.005	129.23	23.31	12.23
W32	0.244	0.267	0.023	0.144	0.124	-0.020	79.17	20.51	7.01
W33	0.271	0.286	0.015	0.218	0.204	0.014	89.93	21.16	7.02
W34	0.293	0.301	0.008	0.261	0.277	0.016	100.7	21.94	7.02
W35	0.314	0.324	0.010	0.288	0.297	0.009	111.07	22.60	7.03
W36	0.334	0.349	0.015	0.353	0.386	0.033	121.02	24.33	7.03
W41	0.262	0.233	-0.029	0.239	0.225	-0.014	129.10	22.65	12.22
W42	0.247	0.228	-0.019	0.215	0.214	0.001	109.18	21.63	12.03
W43	0.262	0.242	-0.020	0.220	0.204	-0.016	120.01	22.15	12.02
W44	0.266	0.238	-0.028	0.233	0.208	-0.025	130.34	22.81	12.04
W45	0.297	0.303	-0.006	0.278	0.274	-0.004	141.09	24.05	12.01
W46	0.309	0.305	0.004	0.322	0.305	0.017	151.23	25.68	12.01

RMS error = Square Root((Sum[(Error)squared])/n)

Crown Width RMS = 0.015144"
Root Width RMS = 0.014864"
both Crown and Root = 0.015005"

Calibration Panels:
Voltage Residuals: Material(AL2195) and Panel Thickness (0.200")

V-voltage Measured[volts], V-voltage Predicted[volts],
V-voltage Error[volts],Crown Width[inches],Root Width[inches],
C-current[Amperes],S-fixture speed[Inches Per Minute]

Panel Ref #	V Meas.	V Pred.	V Error	Crown Meas.	Root Meas.	C Meas.	S Meas.
W21	25.45	24.70	-0.75	0.335	0.350	129.00	7.01
W22	23.02	22.10	-0.92	0.269	0.222	118.83	17.11
W23	23.33	22.81	-0.52	0.275	0.230	129.61	17.03
W24	23.59	23.51	-0.08	0.280	0.225	140.20	17.00
W25	24.14	24.34	0.20	0.285	0.237	151.04	16.98
W26	24.67	25.15	0.48	0.300	0.252	161.13	17.00
W31	23.31	23.36	0.05	0.290	0.253	129.23	12.23
W32	20.51	20.57	0.06	0.244	0.144	79.17	7.01
W33	21.16	21.26	0.10	0.271	0.218	89.93	7.02
W34	21.94	22.02	0.08	0.293	0.261	100.7	7.02
W35	22.60	22.76	0.16	0.314	0.288	111.07	7.03
W36	24.33	23.85	-0.48	0.334	0.353	121.02	7.03
W41	22.65	23.14	0.49	0.262	0.239	129.10	12.22
W42	21.63	21.77	0.14	0.247	0.215	109.18	12.03
W43	22.15	22.50	0.35	0.262	0.220	120.01	12.02
W44	22.81	23.28	0.47	0.266	0.233	130.34	12.04
W45	24.05	24.33	0.28	0.297	0.278	141.09	12.01
W46	25.68	25.56	-0.12	0.309	0.322	151.23	12.01

Voltage RMS error = 0.403014V

Test Panel:

When using the empirical weld model to generate weld schedules giving specific weld geometry (root and crown widths), weld voltage must be calculated in order to determine the commanded weld current component of the weld schedule to provide the required power generated needed to achieve the desired root and crown widths.

The three voltage terms B0, B1 and B2 are derived empirically from the three calibration runs.

$$\text{Voltage} = B0 + B1 * Pg + B2 * \text{Speed}$$
$$\text{voltage} = 16.97 + 0.002416 * Pg + -0.121 * \text{velocity}$$

$B0 = 16.97$
$B1 = 0.002416$
$B2 = -0.121$

Pg = Power generated,
Pd = Pg * efficiency = Power delivered

From the weld model parameters derived from the set of calibration panels, a weld schedule was generated from the weld model to produce a weld with specific weld geometry (Crown and Root widths). All AL2195 welds were performed with the torch height held constant at 2mm.

Test Panel:
Material(AL2195) and Panel Thickness (0.200")

Panel Ref #	C Command Amps	S Command IPM	Voltage Predicted	Crown Width Predicted	Root Width Predicted.
T11	130A	12	23.4	.295	.261
T12	110A	7	23.0	.310	.291
T13**	140A	9.5	24.9	.312	.319
T14	120A	14.5	22.2	.269	.217
T15	150A	18	24.3	.280	.239
T16	125A	6	24.1	.324	.344

Test Panel:
Width Residuals: Material(AL2195) and Panel Thickness (0.200")

Panel Ref #	Crown Pred.	Crown Meas.	Crown Error	Root Pred.	Root Meas.	Root Error	C Meas.	V Meas.	S Meas.
T11	.295	.292	-0.003	.261	.240	-0.021	129.07	23.22	12.01
T12	.310	.342	0.032	.291	.342	0.051	113.73	23.52	7.00
T13**	.312	.315	0.003	.319	.495	0.176	140.63	25.63	9.50
T14	.269	.275	0.006	.217	.220	0.003	119.60	22.53	14.45
T15	.280	.275	-0.005	.239	.232	-0.007	151.27	23.83	17.94
T16	.324	.325	0.001	.344	.365	0.021	124.20	25.36	6.02

Crown Width RMS error = 0.012614"
Root Width RMS error = 0.072451"
both Crown and Root = 0.052002"

note: ** indicates cutting

Test Panel:
Voltage Residuals: Material(AL2195) and Panel Thickness (0.200")

Panel Ref #	V Pred.	V Meas.	V Error	Crown Pred.	Crown Meas.	Root Pred.	Root Meas.	C Meas.	S Meas.
T11	23.4	23.22	-0.18	.295	.292	.261	.240	129.07	12.01
T12	23.0	23.52	0.52	.310	.342	.291	.342	113.73	7.00
T13**	24.9	25.63	0.73	.312	.315	.319	.495	140.63	9.50
T14	22.2	22.53	0.33	.269	.275	.217	.220	119.60	14.45
T15	24.3	23.83	-0.47	.280	.275	.239	.232	151.27	17.94
T16	24.1	25.36	1.26	.324	.325	.344	.365	124.20	6.02

Weld Voltage RMS error = 0.677385V

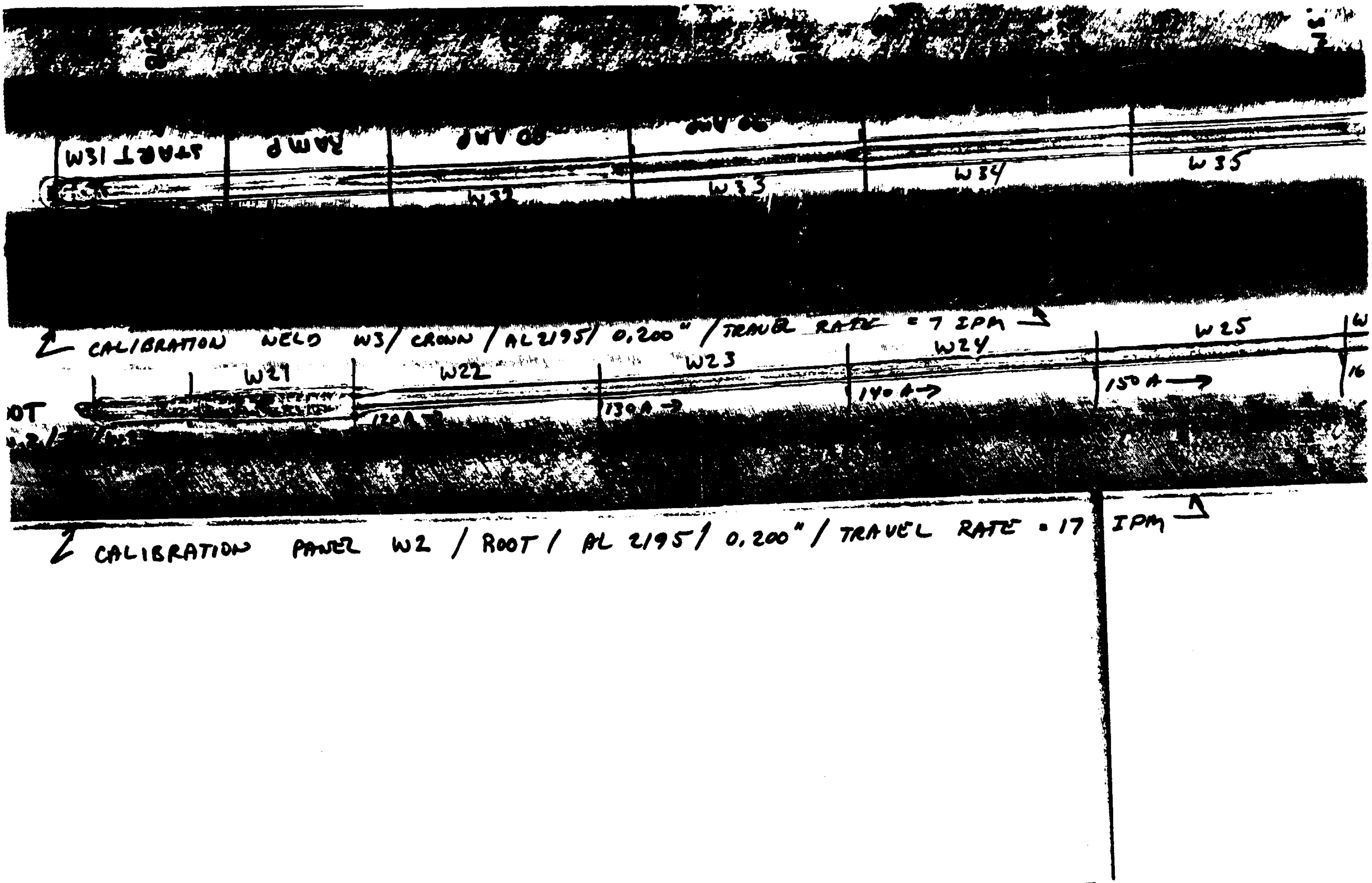
note: ** indicates cutting

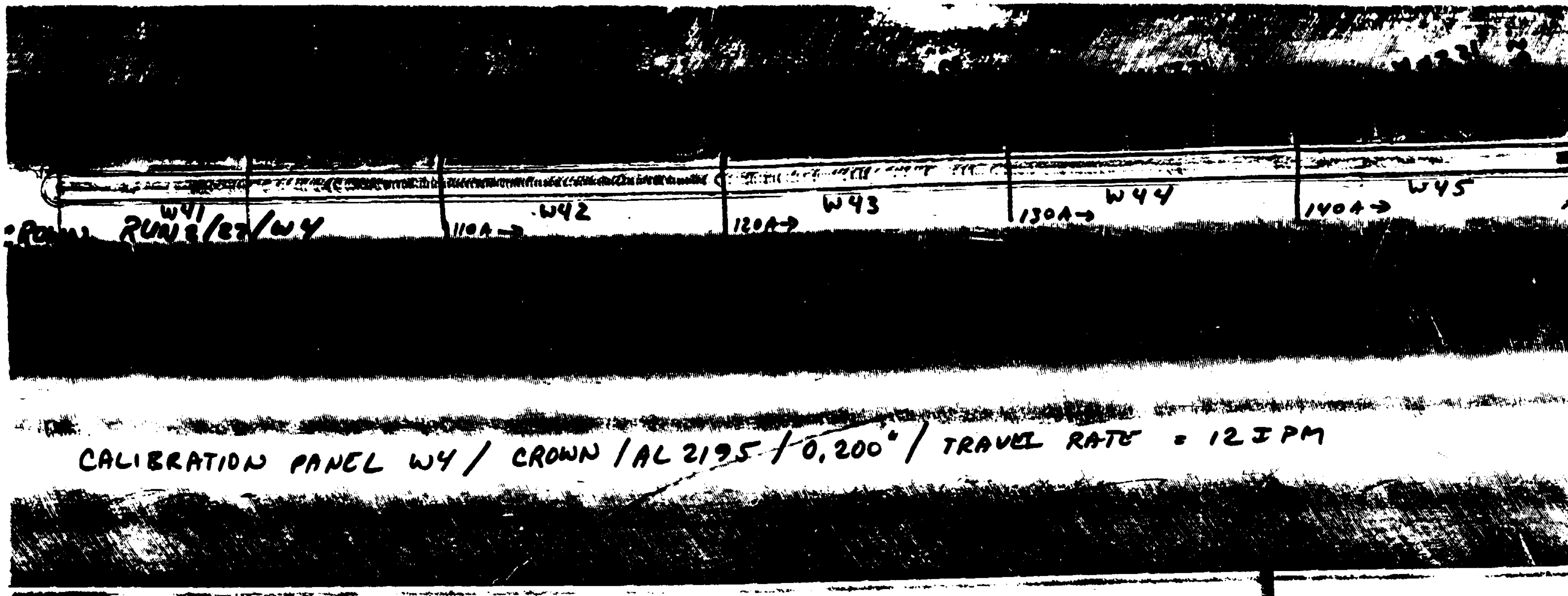
Error between controller calculated crown and root widths and actual measurements of crown and root widths.

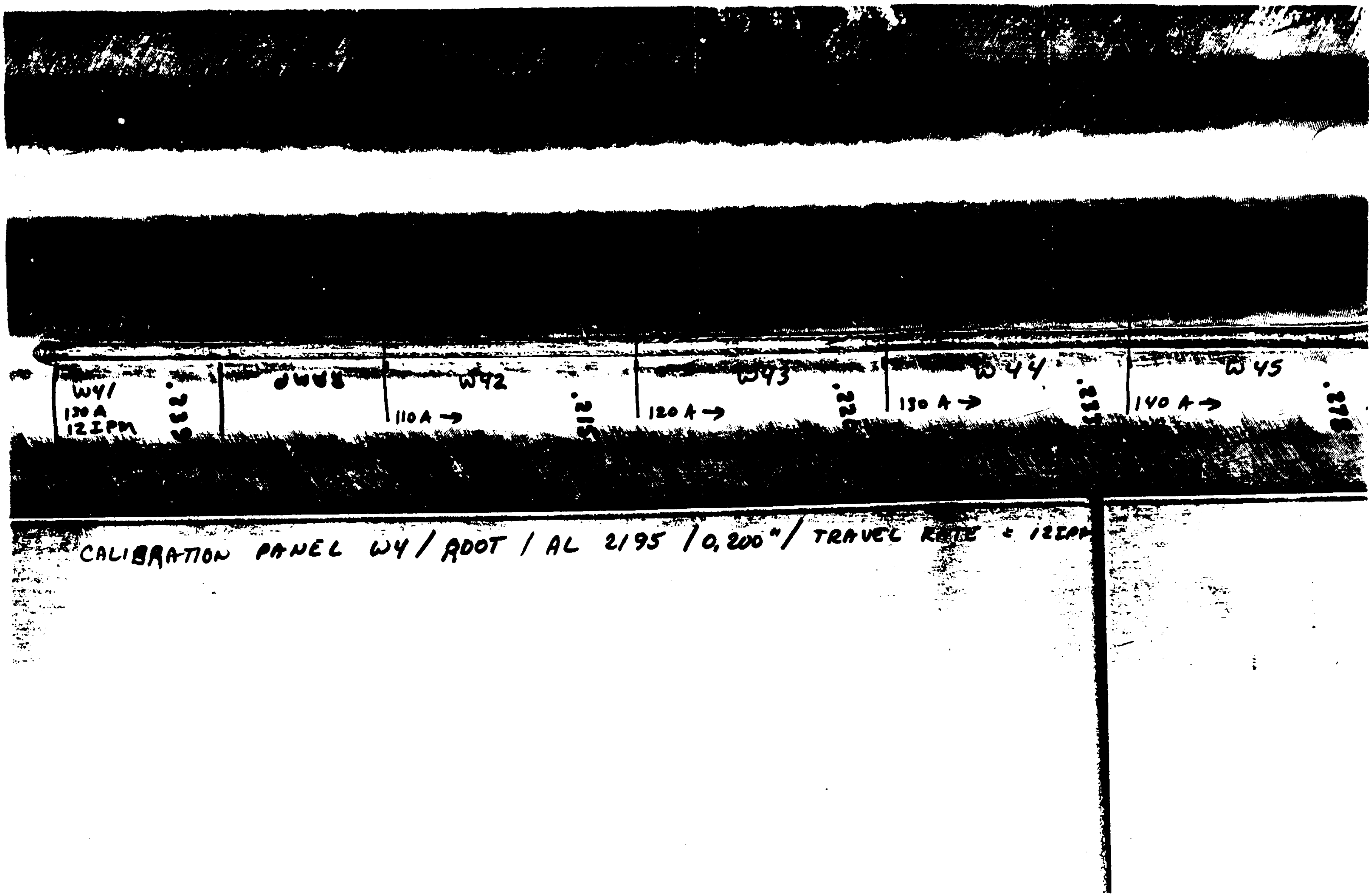
Error Calibration Panels:
Crown Width RMS Error: 0.015144"
Root Width RMS Error: 0.014864"
Both(Average)RMS Error: 0.015005"

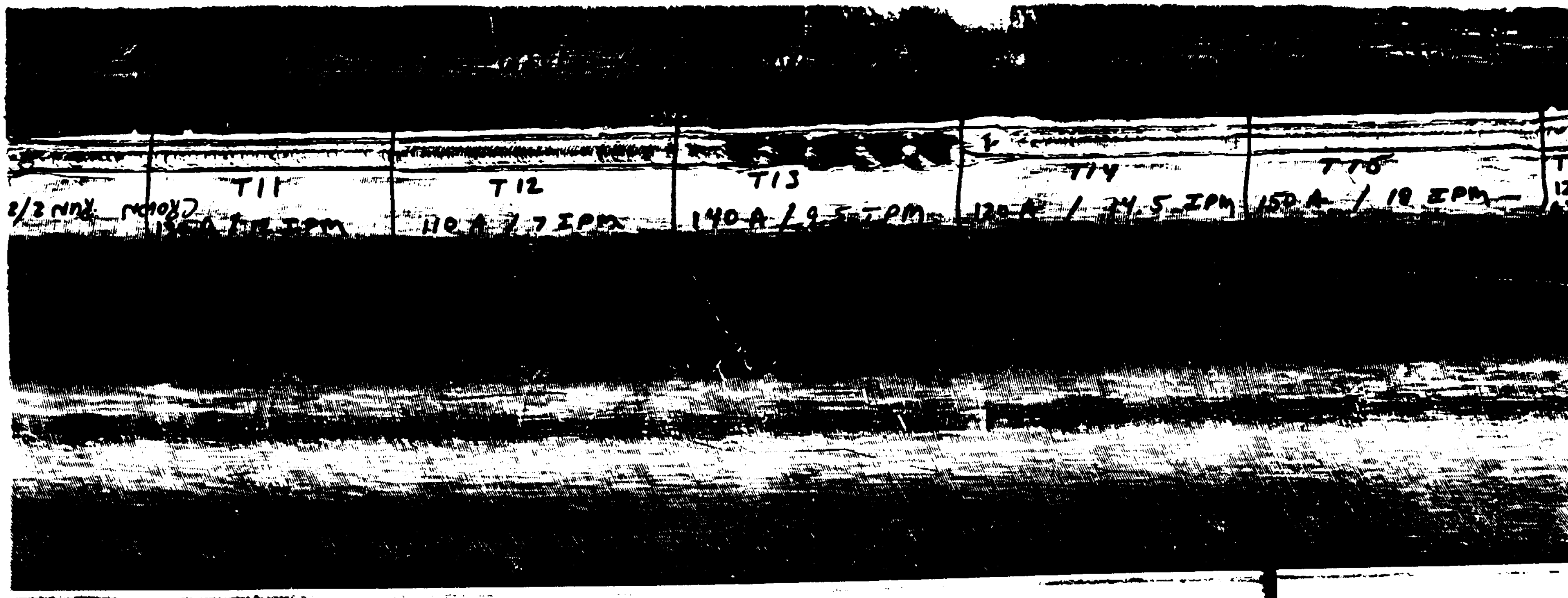
Error Test Panel (with cutting):
Crown Width RMS Error: 0.012614"
Root Width RMS Error: 0.072451"
Both(Average)RMS Error: 0.052002"

Error Test Panel (minus cutting):
Crown Width RMS Error: 0.01479
Root Width RMS Error: 0.026612
Both(Average)RMS Error: 0.022"

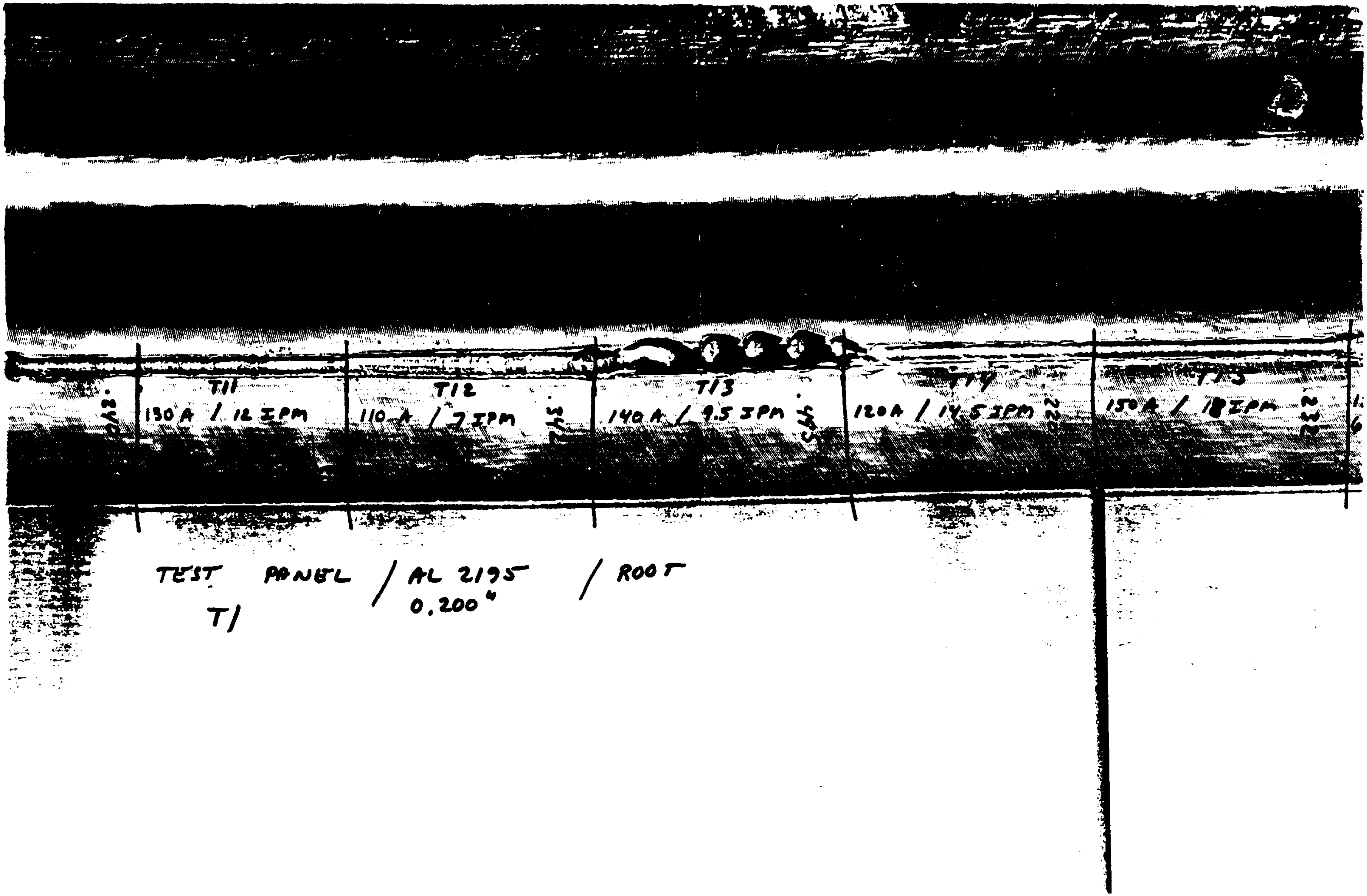

START 15M
RAMP
W31
W32
W33
W34
W35
CALIBRATION WELD W3/ CROWN / AL 2195/ 0,200" / TRAVEL RATE = 7 IPM
W21
W22
W23
W24
W25
120A
130A
140A
150A
CALIBRATION PANEL W2 / ROOT / AL 2195/ 0,200" / TRAVEL RATE = 17 IPM

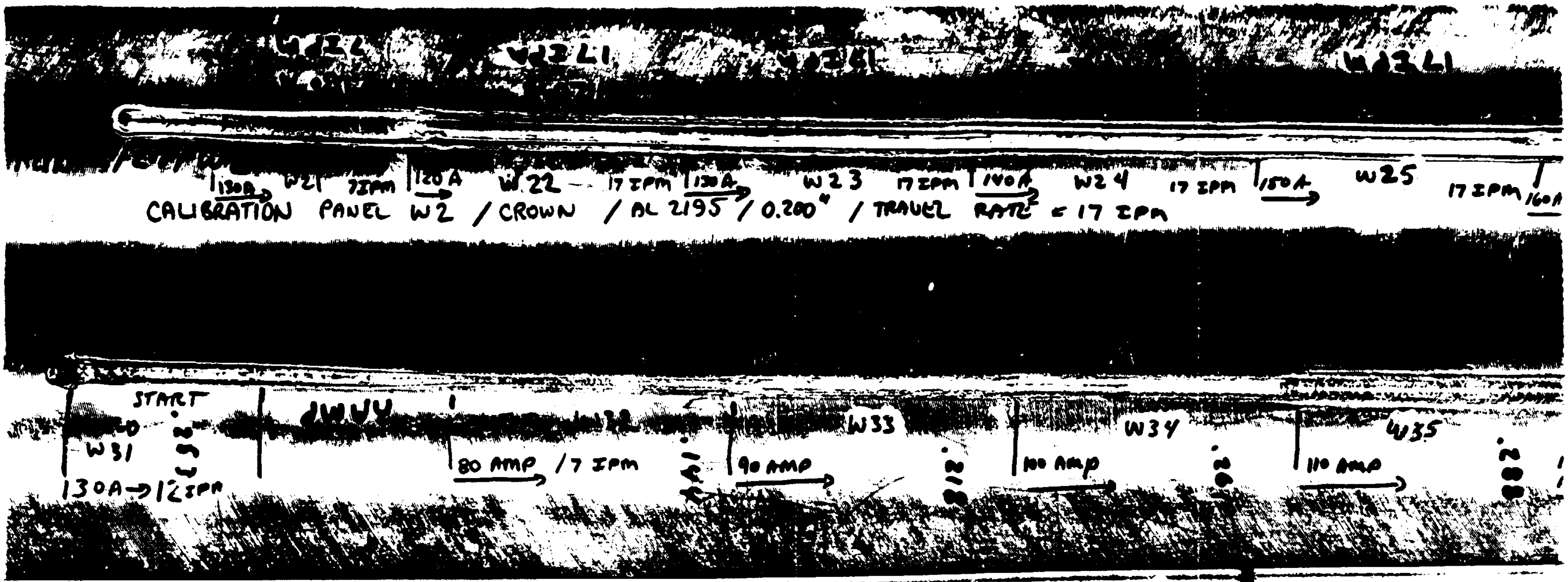

W41
110A →
W42
120A →
W43
130A →
W44
140A →
W45
CALIBRATION PANEL W4 / CROWN / AL 2195 / 0.200" / TRAVEL RATE = 12 IPM


W41
120 A
12IPM
.239
W42
110 A →
.215
W43
120 A →
.226
W44
130 A →
.233
W45
140 A →
.278
CALIBRATION PANEL W4 / ADOT / AL 2195 / 0.200" / TRAVEL



TEST PANEL / AL 2195 / CROWN
T1 0.200"


.240
T11
130 A / 12 IPM
T12
110 A / 7 IPM
.342
T13
140 A / 9.5 IPM
.445
T14
120 A / 14.5 IPM
.220
T15
150 A / 18 IPM
.232
TEST PANEL / AL 2195 / ROOT
0.200"
T1



CALIBRATION PANEL W3 / ROOT / AL2195 / 0.200" / TRAVEL RATE = 7 IPM

Appendix V

11/1/95

To: A. Nunes
From: P. Thompson

Subject: Use of the UAH Model to Generate Controller Parameters

Copies to: P. Buck
P. Milly
D. Stafford

I have written a program that uses the UAH model to generate simulated test panels that may be used to derive controller parameters. Attachment A shows the range of control parameters (current and velocity) and resultant crown and root widths. The data fit produced poor results (Attachment B) when compared to the empirical data (Attachment D) and applying the UAH derived control parameters to the actual test data yielded a performance that is probably unacceptable (Attachment C), i.e. a RMS root error of 4mm.

The cause of the poor data fit seems to be the result of erratic model performance. The following table shows that small changes in parameters can make large changes in predictions (the controller logic and fit process make assumptions about the continuity of the weld process)

UAH Model prediction 0.25" AL2219
Weld Speed 10 "/min

	Current	Crown	Root	
	125.00	6.764	3.657	
	125.01	6.765	3.658	
	125.02	6.765	3.659	
	125.03	6.766	3.660	
*******>	125.04	6.565	4.698	<*******
	125.05	6.565	4.700	
	125.06	6.565	4.701	
	125.07	6.565	4.703	
	125.08	6.565	4.706	
	125.09	6.565	4.708	
	125.10	6.565	4.710	

This problem could be in the

1. Original UAH Fortran
2. Conversion to MacIntosh C
3. Conversion from MacIntosh C to IBM PC C.

The best method to resolve the difficulty would be to have Boeing run the same tests and see if the problem exists in their code. If not, it is an IBM problem. If so, then the original Fortran should be tested.

Another approach to generalizing the controller could be to use the normalized variables developed by A. Nunes. We have, for example, empirical controller parameters for steel. If the normalized versions of these parameters compare with the values for AL2219, then the controller could be expanded without requiring the UAH model.

Attachment A

Generate Panels

```
(cs) Start current      -  100.00
(ce) End current        -  150.00
(cn) Number current     -      10
(vs) Start velocity     -    8.00
(ve) End velocity       -   15.00
(vn) Number velocity    -       7

(r)everse ratio         -   0.900
(m)odel                 - UAH
(g)enerate

        or e(x)it
```

```
Current -> 100.00 Velocity ->  8.0 Crown ->  6.627 Root ->  3.014
Current -> 100.00 Velocity ->  9.0 Crown ->  6.255 Root ->  1.000
Current -> 100.00 Velocity -> 10.0 Crown ->  5.895 Root ->  0.000
Current -> 100.00 Velocity -> 11.0 Crown ->  5.776 Root ->  0.000
Current -> 100.00 Velocity -> 12.0 Crown ->  5.590 Root ->  0.000
Current -> 100.00 Velocity -> 13.0 Crown ->  5.306 Root ->  0.000
Current -> 100.00 Velocity -> 14.0 Crown ->  5.621 Root ->  0.000
Current -> 100.00 Velocity -> 15.0 Crown ->  5.465 Root ->  0.000
Current -> 105.00 Velocity ->  8.0 Crown ->  6.530 Root ->  5.062
Current -> 105.00 Velocity ->  9.0 Crown ->  6.419 Root ->  1.550
Current -> 105.00 Velocity -> 10.0 Crown ->  6.101 Root ->  0.000
Current -> 105.00 Velocity -> 11.0 Crown ->  5.865 Root ->  0.000
Current -> 105.00 Velocity -> 12.0 Crown ->  5.710 Root ->  0.000
Current -> 105.00 Velocity -> 13.0 Crown ->  5.433 Root ->  0.000
Current -> 105.00 Velocity -> 14.0 Crown ->  5.277 Root ->  0.000
Current -> 105.00 Velocity -> 15.0 Crown ->  5.591 Root ->  0.000
Current -> 110.00 Velocity ->  8.0 Crown ->  6.607 Root ->  5.451
Current -> 110.00 Velocity ->  9.0 Crown ->  6.492 Root ->  2.273
Current -> 110.00 Velocity -> 10.0 Crown ->  6.262 Root ->  1.000
Current -> 110.00 Velocity -> 11.0 Crown ->  5.990 Root ->  0.000
Current -> 110.00 Velocity -> 12.0 Crown ->  5.785 Root ->  0.000
Current -> 110.00 Velocity -> 13.0 Crown ->  5.652 Root ->  0.000
Current -> 110.00 Velocity -> 14.0 Crown ->  5.370 Root ->  0.000
Current -> 110.00 Velocity -> 15.0 Crown ->  5.250 Root ->  0.000
Current -> 115.00 Velocity ->  8.0 Crown ->  6.813 Root ->  6.219
Current -> 115.00 Velocity ->  9.0 Crown ->  6.709 Root ->  3.480
Current -> 115.00 Velocity -> 10.0 Crown ->  6.413 Root ->  1.477
Current -> 115.00 Velocity -> 11.0 Crown ->  6.023 Root ->  0.000
Current -> 115.00 Velocity -> 12.0 Crown ->  5.906 Root ->  0.000
Current -> 115.00 Velocity -> 13.0 Crown ->  5.726 Root ->  0.000
Current -> 115.00 Velocity -> 14.0 Crown ->  5.521 Root ->  0.000
Current -> 115.00 Velocity -> 15.0 Crown ->  5.340 Root ->  0.000
Current -> 120.00 Velocity ->  8.0 Crown ->  6.914 Root ->  6.558
Current -> 120.00 Velocity ->  9.0 Crown ->  6.597 Root ->  5.341
Current -> 120.00 Velocity -> 10.0 Crown ->  6.553 Root ->  2.434
Current -> 120.00 Velocity -> 11.0 Crown ->  6.307 Root ->  1.000
Current -> 120.00 Velocity -> 12.0 Crown ->  5.954 Root ->  0.000
```

```
Current -> 120.00 Velocity -> 13.0 Crown ->  5.858 Root ->  0.000
Current -> 120.00 Velocity -> 14.0 Crown ->  5.696 Root ->  0.000
Current -> 120.00 Velocity -> 15.0 Crown ->  5.459 Root ->  0.000
Current -> 125.00 Velocity ->  8.0 Crown ->  7.183 Root ->  7.181
Current -> 125.00 Velocity ->  9.0 Crown ->  6.702 Root ->  6.100
Current -> 125.00 Velocity -> 10.0 Crown ->  6.764 Root ->  3.657
Current -> 125.00 Velocity -> 11.0 Crown ->  6.406 Root ->  1.614
Current -> 125.00 Velocity -> 12.0 Crown ->  6.247 Root ->  1.000
Current -> 125.00 Velocity -> 13.0 Crown ->  5.921 Root ->  0.000
Current -> 125.00 Velocity -> 14.0 Crown ->  5.841 Root ->  0.000
Current -> 125.00 Velocity -> 15.0 Crown ->  5.693 Root ->  0.000
Current -> 130.00 Velocity ->  8.0 Crown ->  7.619 Root ->  7.617
Current -> 130.00 Velocity ->  9.0 Crown ->  6.788 Root ->  6.787
Current -> 130.00 Velocity -> 10.0 Crown ->  6.620 Root ->  5.526
Current -> 130.00 Velocity -> 11.0 Crown ->  6.633 Root ->  2.928
Current -> 130.00 Velocity -> 12.0 Crown ->  6.312 Root ->  1.000
Current -> 130.00 Velocity -> 13.0 Crown ->  6.073 Root ->  0.000
Current -> 130.00 Velocity -> 14.0 Crown ->  5.883 Root ->  0.000
Current -> 130.00 Velocity -> 15.0 Crown ->  5.817 Root ->  0.000
Current -> 135.00 Velocity ->  8.0 Crown ->  8.140 Root ->  8.138
Current -> 135.00 Velocity ->  9.0 Crown ->  7.212 Root ->  7.210
Current -> 135.00 Velocity -> 10.0 Crown ->  6.835 Root ->  6.221
Current -> 135.00 Velocity -> 11.0 Crown ->  6.588 Root ->  5.119
Current -> 135.00 Velocity -> 12.0 Crown ->  6.571 Root ->  2.486
Current -> 135.00 Velocity -> 13.0 Crown ->  6.274 Root ->  1.000
Current -> 135.00 Velocity -> 14.0 Crown ->  6.056 Root ->  0.000
Current -> 135.00 Velocity -> 15.0 Crown ->  5.879 Root ->  0.000
Current -> 140.00 Velocity ->  8.0 Crown ->  7.986 Root ->  7.984
Current -> 140.00 Velocity ->  9.0 Crown ->  7.066 Root ->  7.064
Current -> 140.00 Velocity -> 10.0 Crown ->  6.688 Root ->  6.076
Current -> 140.00 Velocity -> 11.0 Crown ->  6.570 Root ->  4.829
Current -> 140.00 Velocity -> 12.0 Crown ->  6.504 Root ->  2.018
Current -> 140.00 Velocity -> 13.0 Crown ->  6.219 Root ->  1.000
Current -> 140.00 Velocity -> 14.0 Crown ->  5.992 Root ->  0.000
Current -> 140.00 Velocity -> 15.0 Crown ->  5.835 Root ->  0.000
Current -> 145.00 Velocity ->  8.0 Crown ->  7.999 Root ->  7.997
Current -> 145.00 Velocity ->  9.0 Crown ->  7.078 Root ->  7.076
Current -> 145.00 Velocity -> 10.0 Crown ->  6.690 Root ->  6.094
Current -> 145.00 Velocity -> 11.0 Crown ->  6.572 Root ->  4.854
Current -> 145.00 Velocity -> 12.0 Crown ->  6.509 Root ->  2.050
Current -> 145.00 Velocity -> 13.0 Crown ->  6.224 Root ->  1.000
Current -> 145.00 Velocity -> 14.0 Crown ->  5.996 Root ->  0.000
Current -> 145.00 Velocity -> 15.0 Crown ->  5.839 Root ->  0.000
Current -> 150.00 Velocity ->  8.0 Crown ->  8.144 Root ->  8.141
Current -> 150.00 Velocity ->  9.0 Crown ->  7.215 Root ->  7.213
Current -> 150.00 Velocity -> 10.0 Crown ->  6.836 Root ->  6.225
Current -> 150.00 Velocity -> 11.0 Crown ->  6.588 Root ->  5.125
Current -> 150.00 Velocity -> 12.0 Crown ->  6.572 Root ->  2.493
Current -> 150.00 Velocity -> 13.0 Crown ->  6.275 Root ->  1.000
Current -> 150.00 Velocity -> 14.0 Crown ->  6.057 Root ->  0.000
Current -> 150.00 Velocity -> 15.0 Crown ->  5.880 Root ->  0.000
```

Attachment B

UAH Controller applied against UAH data

alpha = -5.2899e-02 + -1.5862e-04 * pg + 4.0059e-04 * pd, where

alpha = power distribution parameter (i.e. crown vs. root)
pg = power generated
pd = power delivered = efficiency * pg.

Jc 0.76394 mean 0.02806

Panel ID	Power in	Current	Speed	Shield Flow	Root Error	Effc
0000	2119.97	100.00	8.00	61.60	1.480	54.81
0100	2225.97	105.00	8.00	61.60	0.301	52.55
0200	2331.97	110.00	8.00	61.60	0.363	50.89
0300	2437.97	115.00	8.00	61.60	0.757	49.66
0301	2437.97	115.00	9.00	61.60	1.559	51.21
0400	2543.97	120.00	8.00	61.60	0.741	48.33
0401	2543.97	120.00	9.00	61.60	0.039	49.36
0500	2649.97	125.00	8.00	61.60	0.949	47.44
0501	2649.97	125.00	9.00	61.60	0.468	48.13
0502	2649.97	125.00	10.00	61.60	1.609	49.86
0600	2755.96	130.00	8.00	61.60	0.912	46.93
0601	2755.96	130.00	9.00	61.60	0.822	46.96
0602	2755.96	130.00	10.00	61.60	0.016	48.13
0700	2861.96	135.00	8.00	61.60	0.929	46.61
0701	2861.96	135.00	9.00	61.60	0.808	46.56
0702	2861.96	135.00	10.00	61.60	0.366	47.32
0703	2861.96	135.00	11.00	61.60	0.299	48.20
0800	2967.96	140.00	8.00	61.60	0.453	45.17
0801	2967.96	140.00	9.00	61.60	0.380	45.11
0802	2967.96	140.00	10.00	61.60	0.033	45.81
0803	2967.96	140.00	11.00	61.60	0.855	46.93
0900	3073.96	145.00	8.00	61.60	0.091	44.11
0901	3073.96	145.00	9.00	61.60	0.058	44.05
0902	3073.96	145.00	10.00	61.60	0.315	44.71
0903	3073.96	145.00	11.00	61.60	1.104	45.80
1000	3179.96	150.00	8.00	61.60	0.185	43.34
1001	3179.96	150.00	9.00	61.60	0.181	43.30
1002	3179.96	150.00	10.00	61.60	0.529	43.98
1003	3179.96	150.00	11.00	61.60	1.116	44.78

Attachment C

UAH Controller applied against experimental data

Jc 4.18706 mean 4.03428

Panel ID	Power in	Current	Speed	Shield Flow	Root Error	Effc
02A-B	4282.56	139.70	8.10	93.70	5.874	37.28
02A-C	3900.99	129.20	8.10	94.40	4.705	38.79
02A-D	3218.79	109.80	8.10	94.80	3.286	42.99
02A-E	3907.69	129.30	8.10	95.40	4.856	39.09
03A-B	4401.01	144.70	8.20	93.60	6.569	37.03
03A-C	3101.42	105.80	8.20	94.70	3.000	44.03
03A-D	4413.71	144.70	8.20	95.10	6.788	37.15
03A-E	3377.75	114.10	8.10	95.70	3.572	41.76
04A-B	3893.97	129.80	9.00	95.20	4.240	40.20
04A-C	3935.17	129.90	8.20	95.70	5.050	38.89
04A-D	3932.02	129.80	7.20	96.20	5.911	37.91
04A-E	3622.84	125.00	8.70	96.80	3.321	41.96
05A-B	3901.79	129.90	6.60	95.70	6.581	37.35
05A-C	3887.16	130.00	8.10	96.40	5.149	38.94
05A-D	3903.94	129.70	10.10	96.80	3.636	41.09
05A-E	3745.64	127.70	8.10	97.30	4.767	40.11
2A	3894.84	132.00	9.80	61.30	3.015	41.45
2B	3875.56	131.90	8.90	61.00	4.266	40.76
2C	3869.54	132.40	10.80	61.70	3.004	41.91
2D	3867.35	132.10	11.70	61.70	2.584	42.84
2E	3850.39	133.00	11.70	61.80	2.736	42.94
2F	3852.54	132.00	9.80	61.50	3.444	41.76
2G	3852.78	132.50	8.90	61.30	4.565	40.79
2H	3863.19	132.60	10.80	60.90	3.136	42.66
2I	3834.24	132.70	10.70	61.30	3.275	42.19
2J	3891.66	132.10	9.80	61.20	3.862	40.80
2K	3862.53	132.10	11.70	60.60	2.773	43.08
2L	3842.59	132.70	8.70	61.00	4.883	40.18
3M	3869.89	132.70	9.70	62.20	3.191	41.03
3R	3851.40	131.70	9.70	61.30	3.665	41.31
3V	3843.96	131.80	9.70	60.80	3.472	40.31
5A	3785.88	133.30	9.50	62.20	3.426	41.63
5D	3803.59	132.60	9.60	61.80	3.785	41.43
6A	3838.50	132.30	9.70	61.60	3.055	41.02
6B	3798.19	132.80	10.80	61.70	3.727	42.18
6C	3817.43	133.10	8.90	61.20	4.222	40.75
6D	3356.71	118.50	10.90	61.20	2.612	46.59
6E	3360.37	118.10	9.90	61.60	3.002	44.92
6F	3339.60	118.10	9.00	61.20	3.364	43.81
6G	4381.30	147.70	9.00	61.40	5.407	37.49
6H	4345.09	146.30	10.00	61.40	4.758	39.17
6I	4342.72	147.90	10.90	61.80	3.712	39.69
7A1	3472.32	121.80	9.50	92.20	3.982	42.90
7A2	4191.25	141.90	9.50	92.20	5.023	38.90

7A3	5023.37	162.20	9.50	92.10	6.359	36.43
9A	3778.76	132.70	9.90	61.70	3.848	42.07
9B	3325.03	118.00	10.40	62.20	1.965	45.54
9E	4303.82	147.80	9.50	65.20	4.518	38.92
9F	3784.19	133.50	10.00	64.90	3.954	41.88
9I	4384.90	147.70	9.40	60.30	4.913	38.38
9J	3365.26	118.20	10.40	61.70	2.565	44.97
9M	3361.22	117.70	10.40	62.20	2.821	45.74
9N	3775.95	133.40	9.90	62.20	3.458	42.43
9Q	3880.83	132.40	9.90	62.10	3.780	40.78
9R	4409.88	147.80	9.40	62.00	4.848	37.82
9U	3425.06	118.00	10.40	62.00	2.790	44.46
9V	4456.97	147.40	9.50	62.10	4.887	38.01

Attachment D

Empirical Model 0.25" AL2219

alpha = 0.13 - 0.000047331 * pg + 0.000099262 * pd

Jc 0.32819 mean -0.00214

Panel ID	Power in	Current	Speed	Shield Flow	Root Error	Effc
02A-B	4282.56	139.70	8.10	93.70	-0.135	33.04
02A-C	3900.99	129.20	8.10	94.40	-0.434	35.00
02A-D	3218.79	109.80	8.10	94.80	-0.270	40.23
02A-E	3907.69	129.30	8.10	95.40	-0.221	35.38
03A-B	4401.01	144.70	8.20	93.60	0.413	32.69
03A-C	3101.42	105.80	8.20	94.70	-0.241	41.50
03A-D	4413.71	144.70	8.20	95.10	0.654	32.85
03A-E	3377.75	114.10	8.10	95.70	-0.356	38.72
04A-B	3893.97	129.80	9.00	95.20	-0.066	36.81
04A-C	3935.17	129.90	8.20	95.70	-0.043	35.13
04A-D	3932.02	129.80	7.20	96.20	-0.140	33.88
04A-E	3622.84	125.00	8.70	96.80	-0.512	39.04
05A-B	3901.79	129.90	6.60	95.70	-0.106	33.18
05A-C	3887.16	130.00	8.10	96.40	0.062	35.19
05A-D	3903.94	129.70	10.10	96.80	-0.017	37.96
05A-E	3745.64	127.70	8.10	97.30	0.110	36.68
2A	3894.84	132.00	9.80	61.30	-0.661	38.42
2B	3875.56	131.90	8.90	61.00	0.059	37.53
2C	3869.54	132.40	10.80	61.70	-0.222	39.02
2D	3867.35	132.10	11.70	61.70	-0.204	40.24
2E	3850.39	133.00	11.70	61.80	-0.027	40.37
2F	3852.54	132.00	9.80	61.50	-0.138	38.82
2G	3852.78	132.50	8.90	61.30	0.384	37.57
2H	3863.19	132.60	10.80	60.90	0.077	40.01
2I	3834.24	132.70	10.70	61.30	0.095	39.38
2J	3891.66	132.10	9.80	61.20	0.041	37.58
2K	3862.53	132.10	11.70	60.60	0.035	40.55
2L	3842.59	132.70	8.70	61.00	0.469	36.78
3M	3869.89	132.70	9.70	62.20	-0.605	37.88
3R	3851.40	131.70	9.70	61.30	-0.056	38.23
3V	3843.96	131.80	9.70	60.80	-0.461	36.94
5A	3785.88	133.30	9.50	62.20	-0.260	38.64
5D	3803.59	132.60	9.60	61.80	0.082	38.39
6A	3838.50	132.30	9.70	61.60	-0.722	37.86
6B	3798.19	132.80	10.80	61.70	0.588	39.35
6C	3817.43	133.10	8.90	61.20	0.059	37.51
6D	3356.71	118.50	10.90	61.20	0.457	44.91
6E	3360.37	118.10	9.90	61.60	0.312	42.75
6F	3339.60	118.10	9.00	61.20	0.206	41.32
6G	4381.30	147.70	9.00	61.40	-0.052	33.29
6H	4345.09	146.30	10.00	61.40	0.317	35.49
6I	4342.72	147.90	10.90	61.80	-0.226	36.18
7A1	3472.32	121.80	9.50	92.20	0.722	40.19

7A2	4191.25	141.90	9.50	92.20	0.362	35.13
7A3	5023.37	162.20	9.50	92.10	0.255	31.79
9A	3778.76	132.70	9.90	61.70	0.411	39.21
9B	3325.03	118.00	10.40	62.20	-0.477	43.54
9E	4303.82	147.80	9.50	65.20	-0.197	35.16
9F	3784.19	133.50	10.00	64.90	0.506	38.96
9I	4384.90	147.70	9.40	60.30	-0.068	34.45
9J	3365.26	118.20	10.40	61.70	0.012	42.82
9M	3361.22	117.70	10.40	62.20	0.405	43.81
9N	3775.95	133.40	9.90	62.20	0.100	39.67
9Q	3880.83	132.40	9.90	62.10	-0.000	37.55
9R	4409.88	147.80	9.40	62.00	-0.314	33.72
9U	3425.06	118.00	10.40	62.00	0.127	42.19
9V	4456.97	147.40	9.50	62.10	-0.209	33.96

Appendix VI

APPENDIX VI

GENERALIZATION OF EFFICIENCIES THROUGH NONDIMENSIONALIZATION

The power absorption efficiency E and the crown-root power distribution parameter α depend upon a number of system parameters. These system parameters are not independent because each possesses a dimensionality with respect to the fundamental measures: length L, time T, mass M, and temperature θ. It is possible to combine the system parameters into a truly independent set of dimensionless product groups. The number of these groups will be less than the total number of parameters by the number of fundamental measures minus 1. Each of these groups can be seen as a ratio of powers supplied or dissipated in different ways.

For example, suppose the E (and α) depend upon the ratio of welding power Pg generated by the apparatus to the power $2\pi k^*wp^*(Tm-To)$ that a point source moving very slowly would dissipate into an infinite half space of thermal conductivity k, given a temperature Tm at radius wp from the source and an ambient temperature To, where wp is the thickness of a plate for purposes of comparing welds on different geometries. Then

$$E[Pg, k, wp, (Tm-To)] = E[Pg/2\pi kwp(Tm-To)]$$

The dimensionless group can be arrived at mechanically in the following way. The general expression for E as a function of the selected variables can be written as the sum of product terms:

$$E = \sum Pg^{\alpha}\, k^{\beta}\, wp^{\gamma}\, (Tm-To)^{d}$$

These product terms must be dimensionless (like E). The product terms have the dimension:

$$[ML^2/T^3]^{\alpha}[ML/\theta T^3]^{\beta}[L]^{\gamma}[\theta]^{\delta} = M^{\alpha+\beta}\, L^{2\alpha+\beta+\gamma}\, \theta^{-\beta+\delta}\, T^{-3\alpha-3\beta}$$

To meet the requirement of dimensionlessness:

$$\alpha+\beta = 0$$

$$2\alpha+\beta+\gamma = 0$$

$$-\beta+\delta = 0$$

$$-3\alpha-3\beta = 0$$

Noting that the last equation is redundant here, the above equations simplify to:

$\beta = -\alpha$

$\gamma = -\alpha$

$\delta = -\alpha$

So that the equation takes the form of a sum on α of dimensionless terms:

$$E = \sum [Pg/2\pi kwp(Tm\text{-}To)]^{\alpha}$$

or $$E = E[Pg/2\pi kwp(Tm\text{-}To)]$$

But suppose we wish to account for differences in efficiency when the weld width w takes different values with respect to the plate width wp. Then, using the above method, we would be left with two undetermined exponents or, equivalently, two nondimensional groups:

$$E[Pg, k, w, wp, (Tm\text{-}To)] = E[Pg/2\pi kwp(Tm\text{-}To), w/wp]$$

Further, suppose that the ratio of power generated Pg to the power required to melt the forward interface $\rho LeVwwp$, where

ρ = metal density
Le= effective latent heat of metal for transformation at forward interface
V = weld speed

is determinative for the efficiency. This could be the case if the slant of the forward interface adjusts so as to keep $\rho LeVwwp$ approximately constant whatever the value of Pg. This would be a case of

$$E[Pg, \rho, Le, V, w, wp] = E[Pg/\rho LeVwwp, w/wp]$$

It is possible that the effect of still other variables upon E and α may need to be accounted for, for example the effect of plasma gas flow rate. This effect would likely involve a Reynold's number measure of the ratio of inertial to viscous forces in the plasma:

$$Qp\ w/\pi\ dp^2\ \nu p$$

where Qp = plasma gas volume flow rate

dp = diameter of plasma jet column (roughly the same as the torch orifice diameter)

νp = kinematic viscosity of plasma

Not enough information is at hand to make a clear determination of the appropriate nondimensional groups to use to determine E and α, but it is clear that these entities are dependent upon power and velocity. Tentatively the following relation might be fitted to the data:

$$E = E[Pg/\rho LeVwwp,\ Pg/2\pi kwp(Tm-To),\ w/wp,\ Qp\ w/\pi\ dp^2\ \nu p]$$

The nondimensional group relationship correctly representing the physics will, once determined, allow for use of different parameters and will not be tied to the specific situation used to determine the relationship.

Appendix VII

DEFINITIONS

The weld measurements made were crown width, crown height, root width, and root height (figure VII-1). For some welds keyhole leading edge angles were also measured (figure VII-2). Note that the height measurements are for future reference only - they were not used in the analysis or algorithm development. Bead appearances were noted according to the code shown in figure VII-3.

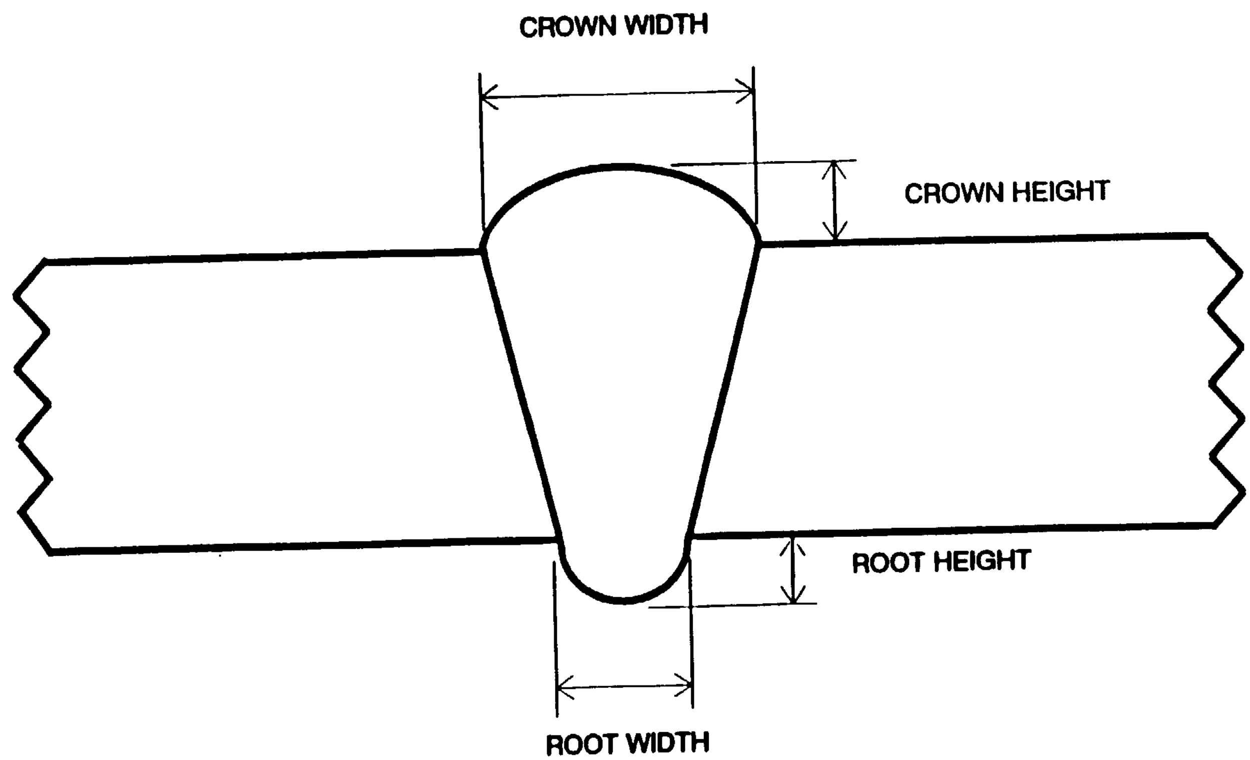


FIGURE VII-1 **Weld Width and Height Definition**

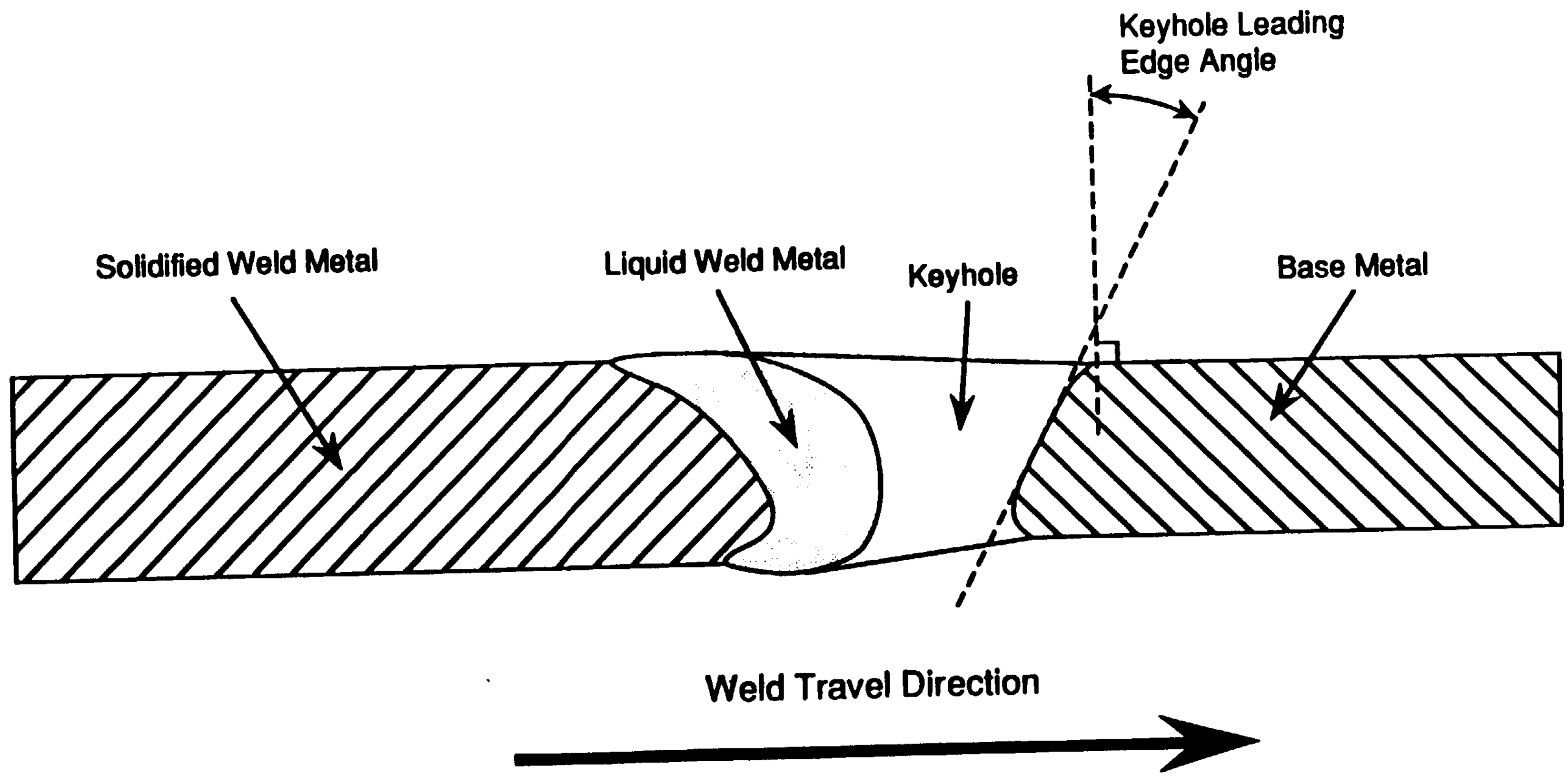
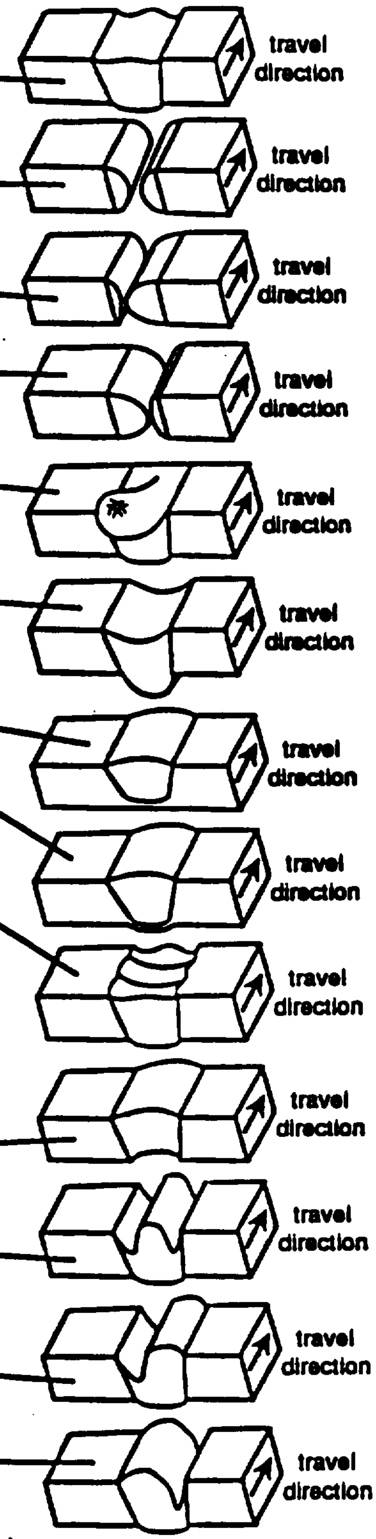


FIGURE VII-2 **Keyhole Leading Edge Angle Definition**

VPPAW MODELING BEAD APPEARANCE CODES

CODE	MEANING
N	Normal Weld (Little or No Undercut)
C	Cutting
LC	Cutting On Left Edge Of Bead
RC	Cutting On Right Edge Of Bead
D	Drooping (Weld Metal Hanging In Blobs)
ED	Excessive Drop-through
PP	Partial Penetration Weld
PT	Pushed Through, But Root Surface Not Fully Melted
R	Ripples (Larger Than Normal) On Crown And Root
RR	Ripples (Larger Than Normal) On Root
S	Shiny Bead Surface
SB	Suckback (Root Weld Surface Below Flush)
U	Undercut (Symmetrical, On Both Edges Of Weld)
LU	Undercut On The Left Edge Of Weld
RU	Undercut On The Right Edge Of Weld
X	Prefix Meaning 'Extreme' (Ex: XU means Extreme Undercut)

APPEARANCE



Notes:
- All Welds Are Full Penetration Unless Denoted 'PP' or 'PT'
- 'U' Used in Conjunction With 'RU' or 'LU' Indicates Undercut is on Both Edges, but Deeper on the Referenced Edge

Weld Bead Appearance Codes FIGURE VII-3

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